PROCEEDINGS

National Conference on Water, Food Security and Climate Change in Sri Lanka Volume 2

Water Quality, Environment and Climate Change

Alexandra Evans and K. Jinapala, editors

IWMI Celebrating 25 years 1985-2010

IWMI International Water Management Institute

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Proceedings of the National Conference on Water, Food Security and Climate Change in Sri Lanka, BMICH, Colombo June 9-11, 2009

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INTERNATIONAL WATER MANAGEMENT INSTITUTE

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Evans, A.; Jinapala, K. (Eds.). 2010. *Proceedings of the National Conference on Water, Food Security and Climate Change in Sri Lanka, BMICH, Colombo, Sri Lanka, 9-11 June 2009. Vol. 2: Water quality, environment and climate change*. Colombo, Sri Lanka: International Water Management Institute. 186p. doi:10.3910/2010.205

/ water quality / river basins / wetlands / water resource management / climate change / rain-fed farming / environmental flows / soil management / case studies / irrigation schemes / models / groundwater / aquifers / wastewater irrigation / Sri Lanka /

ISBN: 978-92-9090-722-0

Cover photo by Mr. Sandaruwan Wickrama, Web Services Officer, International Water Management Institute.

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Acknowledgements

The editors (hereinafter referred to as 'we') greatly appreciate the whole-hearted agreement between the Irrigation Department (ID), Department of Agriculture (DoA) and Hector Kobbakaduwa Agrarian Research and Training Institute (HARTI) to become partners of this conference. We would like to thank the Director General of the Irrigation Department, Mr. H. P. S. Somasiri, the Director General of the Department of Agriculture, Dr. C. Kudagamage, and the Director of HARTI, Mr. V. K. Nanayakkara for being so supportive of the event and encouraging their staff to present papers at the conference. In addition, we acknowledge the support extended by Dr. G. G. A Godaliyadda and H. M. Jayathilaka from ID, Mr. M. M. M. Aheeyar from HARTI and Dr. Kamal Karunagoda from DoA by agreeing to become members of the conference organizing committee that was established by the International Water Management Institute (IWMI). Their valuable contributions were of much benefit in making the conference successful and productive. Mr. B. R. Ariyaratne and Ms. Janitha Godamuduna, from IWMI, also acted as members of the conference organizing committee and provided considerable support in the organization of this national conference.

Funds for the conference were provided by USAID, UNDP/National Disaster Management Centre and Netafim Ltd of Israel. Their generous contributions to this event are much appreciated by us and we extend our sincere thanks to all of them.

We would also like to express our thanks to all the researchers who presented papers at the conference, and for preparing reports for this volume of the conference proceedings, without whom this event would not have been possible. There were many participants from various national and international organizations whose attendance and valuable contributions to the workshop sessions made this event both productive and interesting.

Professor M. S. Swaminathan from India delivered the key-note speech and the Hon. Prime Minister of the Democratic Socialist Republic of Sri Lanka, Rathnasiri Wickremanayaka attended as the chief guest. Both provided us with some very enlightening information and interesting observations, and we are extremely grateful to them for sharing their opinions with us and enriching the conference.

Dr. Colin Chartres, Director General of International Water Management Institute (IWMI), Dr. Madar Samad, Regional Director (IWMI - South Asia) and Dr. Vladimir Smakhtin (Theme Leader-Water Availability and Access-IWMI) provided the encouragement and guidance to organize this nationally important conference. We must say that without their support this conference would not have been the successful event it was.

Finally, our thanks go out to Ms. Pavithra Amunugama, Mr. Joseph Perera, Mr. Nimal Attanayake and Mr. Sumith Fernando for managing the editorial and production process of the proceedings.

The authors would like to acknowledge the International Water Management Institute (IWMI), Irrigation Department (ID), Department of Agriculture (DoA) and the Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI) for their collaboration in conducting the workshop 'National Conference on Water, Food Security and Climate Change in Sri Lanka'.

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This workshop was funded by:

United States Agency for International Development (USAID), Colombo, Sri Lanka

United Nations Development Programme (UNDP), Colombo, Sri Lanka

Netafim Ltd.,
Tel Aviv, Israel

Disaster Management Center, Colombo, Sri Lanka

An Overview: Water Quality, Environment and Climate Change

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Water management, the environment and climate change are all inextricably linked, and yet the issues covered within these areas are diverse, often debated and always interesting. Several of the papers in this volume of the conference proceedings discuss the difficulties of managing water for the environment and people, with some suggesting that integrated water resources management (IWRM) is the way to address the conflicts that are increasingly seen and others presenting new ideas about environmental flows (EFs). Atapattu, de Silva and Senaratna Sellamuttu (Atapattu et al.) for example focus on wetlands and the impacts that upstream activities, principally agriculture, have on wetland integrity. Wetlands provide a multitude of benefits including flood control, water purification, fisheries and recreation, and water is crucial for their maintenance. Likewise it is essential for agricultural production, which leads to water diversions, for what is considered by many to be more productive uses. Consequently conflicts can arise. Atapattu et al. suggest that environmentalists and agriculturalists have worked at crossed purposes but that they now need to enter a new era in which they collaborate, through IWRM processes, to attain benefits for all stakeholders. Abeywickrama has similar opinions and asks how wetlands and irrigation demands can co-exist. Most importantly he questions how to arrive at a balanced, un-politicized solution to water resources management. Both papers use examples from the south of Sri Lanka with Abeywickrama focusing on the Kirindi Oya Irrigation and Settlement Project (KOISP) and Atapattu et al. on Kirindi Oya and Bundala.

The actual water requirements that specific wetlands have is still not adequately known. Dissanayake, Weragala and Smakhtin (Dissanayake et al.) provide a means to assess this and to evaluate the costs and benefits of environmental water allocations, known as Environmental Flows (EF). This is particularly important as arguments for diverting water from the environment are often based on economic assessments but the environment, including wetlands, is not always adequately accounted for in such analyses. Environmental Flows are essentially environmental water allocations, and are discharges of particular magnitude, timing and frequency that are necessary to ensure a range of benefits from a river. Their assessment and provision is considered important for aquatic life but there has been limited exposure to the EF concept in Sri Lanka. Dissanayake et al., therefore, present two case studies of locations where EFs have been calculated. In the Walawe Basin, a simple method of calculating EF is used and the authors demonstrate the feasibility of using it in basins with limited hydrological data. In the Menik Ganga basin, EF assessment is used to evaluate the costs and benefits of water allocation.

Weligamage, Butcher, Blatner, Shumway and Giordano (Weligamage et al.) are also interested in how environmental benefits can be valued and use a non-market valuation method to estimate the economic value of a committed flow through a unique ecosystem, the Yala Protected Area Complex (YPC), also in the south of Sri Lanka. Maintenance of the YPC's ecosystem depends on the flow of the Menik Ganga, which could reduce in future years if farmers demand increased releases from the Veheragala Reservoir. Using a willingness to pay (WTP) survey, Weligamage et al. show that 65 % of the population is willing to pay to maintain the ecosystems, with a mean WTP for water releases of Sri Lankan Rupees (SLR) 435 per year, resulting in a present value of aggregate WTP of is SLR 12 billion over a 10-year payment horizon.

The impact of agriculture on wetlands not only arises as a result of water diversion but also due to pollutants, especially sediment and agro-chemicals. Atapattu et al. raise the issue of eutrophication and siltation of coastal water bodies, including the Kalametiya Lagoon, while Amarasekara and Kumarihamy look into this in more detail in a study of 150 farmers in Kurundy Oya in the Upper Mahaweli catchment. In this area both paddy and vegetable cultivation take place, but as is the case in many areas in Sri Lanka, increasing population pressure is leading to changes in practices. As a result farming is becoming more intensive, forest and riparian areas are being encroached, fallow periods are no longer maintained and fertilizer is being applied at higher rates. One suggestion to address these issues, especially that of over-fertilization, is to give fertilizer recommendations based on soil tests, rather than blanket recommendations for whole areas. This is of course expensive and difficult to undertake but in the survey farmers stated their WTP, which means that it may be viable for the private sector to become involved.

Sirisena, Rathnayaka and Bandara (Sirisena et al.) propose something similar in their study in Wilgoda, Kurunegala. There, the water used for irrigation is of marginal quality, as it receives urban drainage as the canal flows through the city. Sirisena et al. hypothesize that one of the reasons for the sub-optimal rice yield in Sri Lanka is the depletion and imbalance of nutrients in soils. They suggest that if this could be better understood then site-specific recommendations could be made. However, this is especially complicated in areas where the irrigation water is contaminated with upstream runoff and urban drainage and, therefore, contains unknown concentrations of nutrients, micro-nutrients and pollutants. Their study found that spatial distribution of chemicals is uneven and can vary from chemical to chemical but that in many cases, notably phosphorus (P), soil concentrations decline with distance from irrigation source.

Pesticides also cause pollution and potentially health risks but are much less well understood. Their fate and degradation in the environment is complex and is governed by several processes associated with atmospheric conditions, the surrounding environment, the nature of the chemical and farmer practices. Consequently it is not easy to determine the potential for residues to contaminate surface and groundwater and the impact of this on ecosystems and human health. Analytical techniques are often used to identify chemicals but they are extremely costly and may lack the sensitivity required to detect insecticides, herbicides and fungicides and their degradation products. An alternative approach, therefore, is to understand the fate of pesticides and to adopt best management practices that prevent their movement to sensitive locations while at the same time keeping agricultural productivity high. Watawala, Liyanage and Mallawatantri (Watawala et al.) tested the feasibility of using the Pesticide Impact Rating

Index (PIRI) in three areas in the Hill Country of Sri Lanka: Nuwara Eliya, Walimada and Bandarawela. They found that the PIRI estimated risk was extremely ‘high to high’ for surface water and extremely ‘high to medium’ for groundwater; while the toxicity in both surface and groundwater was ‘high to medium’.

Watawala et al. propose that these findings can be used to explain to farmers how different soil and climatic conditions can influence pesticides. They can also build scenarios to show farmers how different management practices influence the outcomes. This is considered important in Sri Lanka because many farmers use more than the recommended doses ‘to ensure results’, while many in the study said that they were not aware of how the chemicals worked or what the ideal application methods were. Trying to change these practices requires good extension services which can be supported by PIRI. Amarasekara and Kumarihamy also call for more support to farmers, principally through the provision of more field-level extension officers under appropriate government departments as well as institutional strengthening to enforce laws associated with encroachment and soil erosion.

The papers presented in this volume also discuss groundwater quality issues, especially in relation to their suitability for drinking water. Wijesekara and Kudahetty took over 600 samples from shallow wells throughout the Attanagalu Oya Basin and analyzed them for 17 parameters including pH, electrical conductivity, lead and faecal coliforms. They found significant special variation in the quality of the well water and used this to create maps of the most suitable areas to exploit for drinking water.

This need to find more sources of safe drinking water is reflected in the paper on roof rainwater harvesting (RRWH) by Bandara, De Silva and Dayawansa, who assert that stored rainwater can provide accessible, reliable, timely and adequate supplies of water to households, and not only help households to cope at times of water scarcity but also reduce the distance that has to be travelled to collect rainwater. In the study area in Anuradhapura District, 93 % of the households interviewed preferred to use well water for drinking, but in the dry periods this reduced to 27 % and the majority (71 %) chose to use rainwater. However, the use of stored rainwater is limited because of consumer acceptability mainly due to uncertainties about water quality. The study analyzed stored rainwater and found that this concern was not unfounded, with bacterial quality, measured in coliforms, exceeding the Sri Lankan Drinking Water Standards. They also found that in many cases this related to inappropriate management of the system, for example not cleaning the roof and flushing the system or not keeping the tank sealed. If rain water harvesting (RWH) systems are used according to the recommendations then they can become an important part of an integrated water management system specifically to meet domestic water needs, as it has been shown that conditions are suitable for RWH throughout Sri Lanka. However, this will only be possible if people are able to have trust in the systems.

The issue of water scarcity, which has so far been discussed primarily in relation to population growth, competing demands and water pollution, will be considerably effected in the future by climate change. However, it is less clear exactly what those changes will be and many of the papers presented in this volume deal with this issue. It is notable that most projections are at global scales and, therefore, future climate scenarios for Sri Lanka are scarce. The review by Eriyagama and Smakhin found that there is evidence to suggest that Sri Lanka’s climate has already changed with a mean air temperature increase from 1961-1990 of 0.016 ^{0}C (above the global average of 0.013 ^{0}C) and a mean annual rainfall decrease of 144 mm

(7 %) compared to the period 1931-1960. They discuss the implications of climate change predictions for agriculture, water resources, sea level, the plantation sector, the economy and health, suggesting, for example, that there could be reductions in paddy and coconut yields. One prediction is that although the mean annual water availability will increase in Sri Lanka its spatial distribution will not be equitable, so some areas will get drier and others will get wetter, which will have negative impacts on agriculture, with the brunt being borne by the North-East and East. Gunathilaka, Wickramanayake and Perera concern themselves with the potential for floods in Sri Lanka and the link with tidal variations. They consider the implications of these for economic activities and how to predict them and thereby minimize impacts.

Detailed analysis of rainfall data for 22 meteorological stations across Sri Lanka by Senalankadhikara and Manawandu provides some interesting findings. They observed an increase in total rainfall for Jaffna, Pothvil and Mulativue (although some data are missing), compared to a decline in total rainfall in the wet and intermediate zones. They also noted a decline in the number of rainfall days at all monitoring stations except Nuwara Eliya. These changes in rainfall patterns appear to be being felt by paddy farmers whose planting and harvesting patterns have changed over the past 20 years. Paddy is highly susceptible to variations in temperature, rainfall and soil moisture, and Panabokke (1974) proposed a stringent analysis of seasonal rainfall variability to specify the proper choice of sowing dates and the selection of optimum sowing-to-harvest duration, to ensure the maximum chance of rainfall satisfying the crop water demand. This was intended to address the long recognized yield variability in rain-fed agriculture in Sri Lanka. The optimal sowing dates for North Central Sri Lanka resulted in stabilization of yields but Panabokke and Runyawardana report in this volume that by 1986 aberrations in seasonal rainfall patterns were noted with rainfall becoming more varied and more extreme, to the extent that, rather than being occasional, extreme events are now the norm.

These observed changes make it difficult to rely on past experience in agriculture and, therefore, not only does more need to be known about likely future scenarios but it is essential that farmers are able to adapt to climate change and are supported in doing so. Eriyagama and Smakhin found that some adaptation measures had already been put in place in the agricultural sector, including development of low water consuming rice varieties and use of micro-irrigation technologies, and that tools have been developed for predicting seasonal water availability within the Mahaweli Scheme and annual national coconut production, but Sri Lanka has not yet undertaken a comprehensive national study on the vulnerability of its water resources and agriculture to climate change.

How adaptation actually takes place at the individual or household level is perhaps as dependent on local social conditions as it is on the physical environment and infrastructure. Senaratne and Wickramanayake encourage us not to forget this, describing the conditions in communities in the ‘Dry Zone’ of Sri Lanka, in Anuradhapura District, that rely on village tanks for farming. They observe two major adaption strategies: aligning of practices with seasonal rainfall; and management of rainwater in village tanks. How these adaptations take place and are governed is influenced by local institutions that develop around them. However, traditional farming contexts are being transformed by external influences and these introduce complex socioeconomic dimensions to climate change adaptation. Understanding the physical, socioeconomic and institutional aspects of adaptation to climate change will, therefore, be essential to maintain agricultural productivity and incomes.

One potential adaptation to increasing water scarcity brought about either by population pressure or climate change, that is receiving considerable attention in current literature, is that of wastewater reuse. In this volume Udagedara and Najim propose this as an option not only to address scarcity but also as a sound means of wastewater disposal, to protect receiving water bodies and to improve incomes from agriculture in peri-urban areas. The use of wastewater in agriculture is not new in Sri Lanka but was traditionally practiced in homesteads rather than on a town or city level. In Kurunegala, Udagedara and Najim observe that paddy lands are left fallow due to insufficient rainfall or lack of supplementary irrigation. Based on this and the quantity of wastewater produced in the city, they calculate the area that could be brought under production if the wastewater was properly managed.

Wastewater reuse is an interesting adaption option and one which brings the discussion back to water quality, environmental impacts and the sharing of water between various uses, including agriculture, the environment and cities. This volume presents a range of issues in this sphere and makes suggestions for how to tackle some of them, through, for example, IWRM, EFs, more refined climate change predictions, and both physical and social preparation for climate change and adaptation. In some cases the papers open debates and it is hoped the readers and authors will take up and continue to investigate.

How to Minimize the Negative Impacts on Bundala National Park due to Irrigation Development of the Kirindi Oya River Basin

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Abstract

The environment is an important water user, and one that often finds itself at the bottom of the list of priorities when supplies become scare. This research studied how the needs of wetlands can coexist in parallel with irrigation demands and other human activities.

Sri Lanka is a signatory to the Convention on Wetlands of International Importance for Migratory Waterfowl, known as the Ramsar Convention and Bundala Lagoon was declared Sri Lanka's first Ramsar site, a wetland of international importance for migratory waterfowl, in 1990, because of its high bird species richness. The delicate ecological balance of these lagoons will be severely affected by the on-going Weheragala Reservoir project, which is designed to divert excess water from Manike Ganga River basin to Kirindi Oya River basin and the Mala River basin development project. The main negative impacts are eutrophication, accumulation of pesticides and insecticides in the lagoons and siltation, and that lagoons will be converted to fresh water bodies.

This research studied how to minimize these negative impacts using social, economic and engineering tools. The research findings are useful for researches, policymakers and decision-makers, who must find opportunities to improve farmers' incomes and national food production, while and at the same time ensuring sustainable management of wetland ecosystems in Sri Lanka.

Introduction

In Sri Lanka there are two extreme groups: the environmental group with a strong belief that the environment is a holy asset that should be protected at all costs; and the other which is concerned only with financial and economic development, forcing severe actions to overcome poverty in the rural sector and ignoring the environment. Many professionals have joined one of these schools of thought. They play a key role in highlighting this position to the general public and try to implement interventions that match this position, through the existing political authorities. As usual most of the politicians are willing to agree to whichever option that gives them support from the majority of the people.

There is a third group of professionals who hold a balanced opinion on environmental management and economic development, but they find it difficult to raise their voices against the politically supported extreme views. The lack of access to information and knowledge on how to manage environmental issues in tandem with economic development is a constraint to popularizing sustainable development by striking a balance between conservation and production.

It is actually in the interests of national level planners to pay more attention to socio-economic development that makes good and sustainable use of natural resources, and at the same time to consider the fact that a healthy population requires a healthy environment. This will ultimately make development efforts more effective and it is therefore advisable that all parties, even though their views may be divergent, try to work together. The purpose of this research is to develop a sustainable management system by minimizing negative impacts, and to improve the standard of living for farmers in the adjoining areas. The research uses Bundala National Park as a case study.

Context of the Study Area

Lunugamwehera Reservoir was built in the 1980s as part of the Kirindi Oya Irrigaiton and Settlement Project (KOISP), extending a traditional system of ancient ‘tanks’ used to irrigate paddy fields in the Kirindi Oya flood plain for hundreds of years. Typical of recent dam-building schemes in the country, KOISP in not just geared to irrigation for food production but also to development. Delivering water to two extra canals, one each side of the plain, it irrigates some 5,000 hectares of new farmland, created by bulldozing jungle. This new land was offered to 5,000 settler families, mostly from Sri Lanka’s overcrowded wet zone, as well as those displaced by the reservoir, as part of a government scheme to alleviate poverty.

The project has also had its environmental costs. Apart from the ancient tanks and paddy fields under Lunugamwehera Reservoir, the biggest casualty is Bundala National Park. The Park was designated a protected wetland in 1990, which led to the declaration of Bundala as Sri Lanka first Ramsar wetland, a wetland of international importance, especially for migratory water fowl. It is envisaged that visitors will enjoy their visit to Bundala, learn about its biodiversity and contribute towards the conservation of this globally significant eco-system.

Bundala National Park, covering an area of 6,216 ha, is located about 250 km southeast of Colombo in Hambantota District. It is within the south-eastern arid zone of Sri Lanka, where the general climate can be classified as hot and dry with a mean annual temperature of about 27^0C and an average annual rainfall of about 1,074 mm, with the highest monthly rainfall occurring in November. Topographically, the Park is generally flat with sand dunes bordering the coastline. Most agricultural activities are timed to take place within the two wet seasons, the *maha* cropping season from September to January and the *yala* cropping season from April to June.

Three streams, Malala Oya, Embilikala Oya and Kirindi Oya, discharge in to the Park and adjacent areas. The Park consists mainly of dry thorny scrubland and lagoons. The shallow brackish water lagoons located within the Park, Koholankala (390 ha), Malala (650 ha), Embilikala (430 ha) and Bundala (520 ha) form a complex wetland system that harbors a rich bird life, including many species of migratory birds. A total of 197 species have been recorded in the park, over the past several years. These include 139 residents and 58 winter visitors. Among the resident birds, three species are endemic, while 10 species are nationally threatened. Of the migratory species, 46 are regular migrants and 12 are occasional visitors or vagrants.

The highlight of Bundala is the migratory greater flamingo, which visits in large flocks of over 1,000 individuals, from the Rann of Kutch in India. A large flock of flamingo feeding on zooplankton with their filter-feeding beaks is a unique sight in the Bundala Lagoon. From time to time these birds fly from one place in the lagoon to another, in search of new feeding grounds, and their graceful harmonized flight is amazing. It should also be noted that during the past 6 years, a flock of about 350 flamingo have remained in Bundala without returning to their usual breeding grounds.

The beaches within the Bundala park area are an important nesting ground for five marine turtles (only seven marine turtles species are recorded globally) of which three species are endangered marine turtles: the leather back (Dermochelys coriacea), the Oliver Ridley (lepidochelys olivacia); and the green turtle (chelonian mydas). Two further species are threatened marine turtles: the hawks bill and loggerhead. The lagoon systems are prime breeding grounds for fish and other brackish-water life that are essential for the overall biological system and provide both animals and humans with a valuable source of nourishment.

A major reason for the excessive depletion and conversion of wetland resources is failure to adequately account for their non-market environmental values in development decisions. Loss of environmental resource is an economic problem because when these resources degrade or are lost, choices and options are lost and so is value. These may include the loss of both important environmental function and in the case of complex resource system such as wetlands, many important biological resource and amenity values. Many of these values of the natural or managed environmental resource are not bought and sold in markets and they are generally ignored in private and public development decisions. The concept of total economic value provides a framework for the economic valuation of wetlands. Classification of total economic value for wetlands is shown in Table 1.

Table 1. Classification of total economic value for wetlands.

Use Values		Non-use value	
Direct use value	Indirect use values	Option and Quasi option value	Existence value
Fish	Nutrient retention	Future value of information	Biodiversity
Agriculture	Flood control		Bequest value
Fuel–wood	Strom protection		
Recreation	Groundwater recharge		
Transport	External eco-system support		
Wildlife harvesting	Micro–climatic stabilization		

A key concept underlying the principle of the Ramsar Convention is that wetlands have great value and their conservation can only be achieved if this value can be shown to be considerable and in some cases of greater value than the proposed alternative uses of the wetlands site. It may also be necessary to show that conservation is of equally or greater value than an alternative use for the water that is sustaining the wetland. In line with this, contracting parties to the Ramsar Convention are asked to provide the physical and social values of wetlands as a part of the information required for identifying the kind of wetlands that ought to be included in the list of 'Wetlands of International Importance'. They are also required to make environmental impact assessments before initiating schemes that might affect wetlands, and such schemes should pay particular attention to maintaining the values of wetlands.

Problems of Bundala National Park

The eco-systems of the Malala and Embilikala lagoons have been severely affected by the drainage flow from the KOISP and Bandagiriya irrigation schemes. The drainage flow from the Bandagiriya scheme goes to Malala Lagoon and water from tracts 5, 6 and 7 of the right bank of the KOISP flows to Embilikala. Since the KOISP was implemented, the salinity of the lagoons has dropped due to the in-flow of upstream irrigation water. This change in salinity levels has influenced the population of birds as it has affected their food supply. Fortunately, for the past four consecutive years, tracts 5, 6 and 7 have only been cultivated in one season due to water shortages in the scheme, which has positively affected the Embilikala Lagoon.

Eutrophication is an emerging problem in the lagoons. The water has a greenish color as a result of the accumulation of nutrients and increase in filamentous green algae. The main causes are over-grazing which results in animal feces entering surface water and runoff from upstream irrigated areas, which brings fertilizer and soil into the lagoon, as well as other agro-chemicals including insecticides, herbicides and fungicides, especially as these chemicals are sometimes applied in excess of agricultural requirements. Not only does this lead to eutrophication but the pesticides may be toxic and the soil leads to siltation. Grazing of livestock within the conservation area is also problematic because it results in direct competition between livestock and other wildlife such as deer.

Irrigation Development and its Negative Effects on the Bundala Park

The newly completed Mau Ara, Malala Ara diversion project conveys 32 million cubic meters (MCM) per annum to the Malala Ara basin. The total irrigable area of the basin is 2,372 ha but up to *yala* 2003 only 660 ha under the Bandagiriya scheme was cultivated due to water shortages. After the project was completed, cultivation was carried out in the total irrigable area in both *yala* and *maha* seasons. The ultimate result is increased drainage flow to the Malala Lagoon, which is severely threatening the lagoon ecosystem.

The newly started Menik Ganga diversion project will convey 90 MCM per annum to Lunugamvehera Reservoir and the current water shortage will be eliminated after completion of this project. For the past 4 years the right bank tracts 5, 6 and 7 (1,742 ha) have only been cultivated in one out of eight seasons, but after completing this project both *yala* and *maha* can be cultivated and drainage flow to the Embilikala Lagoon will be increased.

It is planned that right bank tracts 3 and 4 (1,800 ha), which are currently uncultivated in both seasons, will be cultivated under KOISP. The drainage water from this scheme will flow to the Bundala Lagoon.

Methodology

The study was undertaken in the right bank tracts 5, 6 and 7, which are managed by seven farmer organizations. A structured questionnaire was used to interview 21 farmers, who were chairmen, treasurers and secretaries of the each farmer organization. These interviewees were selected because they are fully aware of the situation inside their farmer organization boundaries. Officers from relevant organizations were also interviewed, these being: the Department of Wildlife Conservation, the Irrigation Department and the Department of Agriculture. The research was conducted between July and September 2004.

Results

The farmers all had landholdings of 1 ha and family sizes of 4-6. For the past 4 years they have only cultivated in the *maha* season because of water shortages and have cultivated bananas on 202 ha. The household incomes ranged from Rs. 1,666 to Rs. 4,888, which are derived from the sale of other field crops (OFC) and off-farm activities; in general, the income from off-farm activities accounts for 50-64 % of the total.

Even at times of water shortages farmers prefer to grow paddy and choose to grow paddy over OFCs. They also prefer not to cultivate paddy under the ‘dry land farming’ method. If they were to practice this method they would expect to be compensated by a third party if they were to lose their yield.

Ten percent of the sample would like to use micro-irrigation methods but a much larger number (80 %) would do so if the cost was borne by a funding agency. All are practicing direct sowing, which uses a high water volume. If they are transplanting then just 10-12 % of the water is required. Farmers said that they are willing to use alternative practices such as low water use methods and micro-irrigation, but only if a third party is prepared to pay the cost of these. The result of low water methods is that less fresh water will reach Bundala Lagoon, which will be beneficial in maintaining the salinity balance. In addition, if drip irrigation methods are used, this can reduce the fertilizer required by 25-30 %, which will reduce the eutrophication which is taking place.

Similarly, they all are aware of soil conservation but not a single person is applying these measures, although 60 % would be willing to do so if a third party paid the costs. If they did this it would reduce the siltation in Bundala Lagoon.

Farmers would be willing to undertake afforestation in the tract 5, 6 and 7 reservation areas, if they were permitted to receive benefits from this, such as sale of timber. This would also help with soil conservation and reduce their poverty.

None of the farmers practice integrated pest management (IPM) even though it would reduce the quantity of pesticides reaching the lagoon.

Farmers were all aware that cultivation negatively affects Bundala National Park but they are poor and their first priority is to obtain a livelihood for their families. They therefore refuse to stop cultivation and strongly disagree with the idea of water pricing. They are willing to try alternative methods but only if they do not have to bear the costs. They would be happy to do things that simultaneously protected Bundala and increased their families’ income.

Conclusions and Recommendations

Most of the farmers live in poverty and thus they put pressure on available natural resources. They want to protect these resources but not at the expense of their incomes. However, they are increasingly obtaining their incomes from non-farm activities, which may have less of an impact on the Park.

Poverty alleviation in the adjoining area is a major step towards minimizing harmful practices undertaken by farmers. This is because the high level of poverty leads to the abuse of available natural resources. Since poverty alleviation in rural areas first comes from irrigation development, this cannot be sacrificed to conserve Bundala National Park. However, the negative impacts can be reduced, by improving irrigation efficiency, increasing crop productivity and reducing drainage water flow. To achieve these targets, micro-irrigation methods, less water intensive crops, soil conservation methods, afforestation and providing possibilities to engage people in off-farm activities like environment friendly industries, could all be introduced. How such activities should be funded is the question, since the government does not have the capacity to fund such programs.

Bundala National Park is not only an asset to the country but to the world, and global environmental institutions should open there eyes to these types of environmental problems facing developing countries. Finally, at the Third World Water Forum, the International Union for Conservation of Nature (IUCN) committed itself to implementing a project to promote enhanced investment in sustainable ecosystem management within private and public sector participation.

References

Bambaradeniya, C. N. B. (Complier). 2001. Guide to Bundala, ‘A Guide to the Biodiversity of Bundala National Park a Ramsar Wetland in Sri Lanka’. Colombo, Sri Lanka: IUCN.

Kirindi Oya Irrigation and Settlement Project Impact Evaluation Study Volume II. 1998. Colombo, Sri Lanka: International Irrigation Management Institute (IIMI).

Matsuno, Y.; van der hoek, W.; Ranawake, M. 1998. Irrigation Water Management and Bundala National Park. *Proceedings of the Workshop on Water Quality of the Bundala Lagoons*, held in Colombo, Sri Lanka, April 3, 1998, IWMI.

Potential Water Resources for Development of Ruhunupura: Pre-feasibility Study. 2002. Colombo, Sri Lanka: Planning Branch – Irrigation Department, (April 2002).

Silva, T. K.; de Silva, S. B. O.; Kodituwakku, S.; Razaak, M. G. M.; Gunawardana, J.; Ananda, I.M.; Hux, D. 1999. ‘No Future in Farming: The Potential Impact of Commercialization of Non-plantation Agriculture on Rural Poverty in Sri Lanka’. Kandy, Sri Lanka: Centre for Intersectoral Community Health Studies.

The Third World Water Forum. 2003. Final Report, Kyoto, Shiga and Osaka, Japan, (March 16-23, 2003).

‘Wetland Site Report and Conservation Management Plan’. Bundala National Park, Wetland Conservation Project; Central Environmental Authority, (November 1993).

Wetlands and Agriculture – A Case for Integrated Water Resource Management in Sri Lanka

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Abstract

Wetlands are habitats with temporary or permanent accumulation of water. The degradation and loss of wetlands is more rapid than that for other ecosystems, and wetland-dependent biodiversity in many parts of the world is in continuing and accelerating decline. They have been confirmed to deliver a wide range of critical and important services vital for human well-being. Therefore, it is clear that sound wetland management is now expected to not only consider conserving the ecological integrity of the ecosystem but also to pay specific attention to the well-being of local people, thereby contributing to poverty alleviation.

Wetlands, both fresh and marine, have a multitude of benefits, in addition to environmental benefits, such as for agriculture, flood control, water purification, fisheries and recreation. For the maintenance and sustainability of wetlands the crucial requirement is water – a resource that has multiple demands and competition. The main competitor for the water resource around the world is agriculture for food production, a basic requirement for human survival. Therefore, in a situation of wetlands versus food production, the balance tips towards food production without considering the adverse consequences to the wetlands or adequately appreciating the benefits from achieving a balance. This is where Integrated Water Resource Management (IWRM) should be adopted to facilitate this process and enable wetland management and agricultural management to fit into the picture along with the other multiple uses of water.

Integrated Water Resource Management should be of considerable interest for Sri Lanka, being a country which has agriculture very high on the agenda. The country is also home to a range of wetlands including 103 distinct river basins and 42 lagoons, which support a multitude of functions and services to people. The relationship between agriculture and wetlands in Sri Lanka is complex. The proliferation of village level water storage structures (small tanks) has created an unusually large number of man-made wetland habitats that add significantly to the natural wetlands that are concentrated mainly in the coastal belt. The absence of an integrated approach to water resource development however, continues to erode natural wetland systems. Two major problems, which concern downstream fisheries and livelihoods, are high levels of agricultural pollution, especially through the excessive use of fertilizers, and modifications to the hydrology.

The objective of this paper is to review the work of the International Water Management Institute (IWMI) on wetlands and agriculture in Sri Lanka, to look at the competing water demands between water for wetlands and water required for agriculture, keeping in mind the requirements for nature as well as the sustainability of livelihoods. The paper will address some impacts of agriculture on wetlands, the consequences for livelihoods and the benefits of adopting the IWRM approach, building a case on work carried out in the Kirindi Oya and Bundala wetlands.

Introduction

Environmentalists concerned about biological conservation and agriculturalists focused on food production have worked at cross-purposes in wetlands management for a very long time. It is now becoming increasingly clear that the common resource – water – needs to be managed in a manner that benefits all the concerned stakeholders in order to proceed beyond this level of conflict. While the International Water Management Institute's main focus is on water for food production, in terms of wetlands it mainly looks at the inter-relationships and the different uses (multiple uses) of water. Integrated Water Resources Management (IWRM[1]) has been identified as a mechanism to facilitate the balancing of such multiple uses of water. In this context, it is considered that the need to take account of the ecological aspects of agriculture in river basins arose through the realization that water and its uses had to be viewed in a broader integrated management context and all aspects of water use needed to be taken into account in water resources policies (Giordano et al. 2006). This paper will present the competing water demands between water for wetlands and agriculture in Sri Lanka in terms of a trade-off between geographically disjointed benefits and costs within a river basin. It will thus address some impacts of agriculture on wetlands, the consequences for livelihoods and the benefits of adopting the IWRM approach, based on work carried out in the Kirindi Oya and Bundala wetlands.

The Importance of Wetlands

Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is flowing or static, fresh, brackish or saline including areas of marine water, the depth of which at low tide does not exceed 6 meters (Ramsar Convention, Article 1.1, 1971). Wetlands are very important ecosystems due to the services that they provide. These include provisioning services such as food and water, regulating services such as flood regulation, supporting services such as soil formation and nutrient cycling, and lastly, cultural services such as recreation. Some of the major wetland functions identified (see Table 1) for Sri Lanka are mitigation of floods, protection from storms, prevention of coastal erosion; retention of sediments; purification of water; providing a carbon sink; and creating a breeding habitat for edible fish (Finlayson et al. 2005; Kotagama and Bambaradeniya 2006).

[1]"A process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP/TAC 2000).

Two of the most important wetland ecosystem services benefiting human well-being are fish supply and water availability (Finlayson et al. 2005). A critical issue in the twenty-first century is the increasing competition for freshwater between agriculture, domestic use, industry and the environment. On a global scale, more than 70 % of available freshwater has been diverted to agriculture (CA 2007). Water for agriculture depends fundamentally on ecological processes and the services provided by many wetland ecosystems. These waters are often diverted away from inland and coastal wetlands (CA 2007).

Table 1. Wetland ecosystem services and examples.

Services	Examples
Provisioning	
Food	Fish, grain, wild game, fruits and vegetables
Fresh water	Storage and retention of water, agricultural, domestic and industrial use
Fiber and fuel	Logs, fuel wood, peat and fodder
Biochemicals	Medicines and other material from biota
Genetic material	Genes for resistance and ornamental species
Regulating	
Climate regulation	Sink for greenhouse gasses, influence local and regional weather patterns
Water regulation (hydrology)	Groundwater recharge and discharge
Water purification	Retention, recovery and removal of excess nutrients, waste treatment and other pollutants
Erosion regulation	Retention of soils and sediments
Natural hazard regulation	Flood control and storm protection
Pollination	Habitat for pollinators
Cultural	
Spiritual and inspirational	Source of inspiration; many religions attach spiritual and religious values to aspects of wetland ecosystems Opportunities for recreation activities
Recreation Aesthetic	Beauty and aesthetic value in aspects of wetland ecosystems
Educational	Opportunities for formal and informal training
Supporting	
Soil formation	Sediment retention and accumulation of organic matter
Nutrient cycling	Storage, recycling, processing and acquisition of nutrients

Source: Adapted from Finlayson et al. 2005

Wetlands are an integral and vital part of Sri Lanka's ecological and biological diversity and they provide an important habitat for the local flora and fauna (IUCN 2004). The Asian Wetland Directory describes 41 wetland sites of international importance in Sri Lanka covering an area of 274,000 ha (Van Zon 2004). These wetlands can be broadly categorized as: inland natural freshwater wetlands (e.g., rivers, marshes and villus); marine and salt water wetlands (e.g., lagoons, estuaries, mangroves and coral reefs); and man-made wetlands (e.g., tanks, reservoirs, rice fields and salterns).

In Sri Lanka, wetland ecosystems are often indiscriminately exploited for commercial, agricultural, residential and industrial purposes and are also used as a dumping ground for garbage (IUCN 2004). The majority of wetlands in Sri Lanka are facing threats, especially those along the coastal belt (Van Zon 2004; Kotagama and Bambaradeniya 2006). It is important to realize that these issues are not brought about within the wetland itself but are due to activities in the lands adjacent to (Van Zon 2004; Kotagama and Bambaradeniya 2006) and upstream of the wetlands (Atapattu and Molden 2006; Falkenmark et al. 2007), with substantial input from agricultural practices.

However, there is also a necessity to recognize that water for agriculture does have multiple uses and benefits. Especially in countries like Sri Lanka, irrigation schemes and canal systems have made water more abundant and accessible for people. At the community and household level, this water is not only used for agriculture and livestock production but also for bathing, drinking and other domestic applications such as cooking and sanitation (Bakker and Matsuno 2001; DFID 2007). Irrigation contributes significantly to the country's economic growth both in terms of agricultural production as well as hydro-electricity generation. Irrigation infrastructure development has also created inland small-scale subsistence and commercial fisheries. For example, in the Uda Walawe left bank irrigation system in the Ruhuna Basin, there are a number of small and large man-made water bodies called tanks, which form part of the irrigation infrastructure. These tanks support an inland fishery – where the dominant species are tilapia. Before the Uda Walawe Irrigation Project, almost all the mature and large fish were caught during the dry period, leaving only the small juvenile fish during the other seasons, as tanks were seasonal in character. After tank rehabilitation and the creation of new tanks under the irrigation project, a perennial inland fishery was established. Fingerling stocking programs were initiated in these sites by the relevant authorities, in addition to providing communities with fishing gear and boats. Fisheries Societies have also been set up to manage these community fisheries, thereby supporting the livelihoods and the well-being of the local people (Sellamuttu., S. 2008, unpublished project report).

The extensive small tank-based irrigation system that spreads throughout much of the country's dry zone also provides biodiversity refuges, being home to a wide range of Sri Lanka's rich biodiversity, ranging from the Asian Elephant and other mammals to aquatic birds, fish and amphibians. The paddy cultivation systems themselves are considered as artificial seasonal wetlands, according to the Ramsar definition of wetlands, and are often referred to as agro-ecosystems (Falkenmark et al. 2007). The agriculture-wetlands relationship in Sri Lanka is consequently complex owing to both mutual dependence as well as competition for water.

Common Agricultural-related Stresses

The diversion and regulation of water for irrigation has brought about many changes in associated wetlands and ecosystems both internal and coastal (Finlayson 2007). In Sri Lanka, the disappearance of 'Villu' ecosystems[2] in the Mahaweli Floodplains (Kotagama and Bambaradeniya 2006) is an example of inland wetland loss due to irrigation development upstream changing the hydrology of the system, and affecting the environmental flow. Recently there have been several attempts to simulate environmental flows affecting the coastal lagoons, such as Karagan and Bundala, under limited data conditions (Smakhtin and Priyankarage 2003; Smakhtin et al. 2004).

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[2]Relatively small and shallow seasonal water bodies formed in natural depressions and associated with flood plains (Kotagama and Bambaradeniya 2006).

Water quantity is not the only dimension of the wetland ecosystem that is affected by agricultural water use; rather, water diversions and storage structures also affect other aspects of water that are fundamental to downstream wetland ecology, the biodiversity of the wetlands and several coastal livelihoods. Therefore, it is important to look at the quantity, frequency, timing and quality of the water flow.

Agricultural activities in the river basin, especially the use of agrochemicals, which can leach out into the drainage water bodies, are often responsible for the degradation of water quality in the downstream wetland areas. Sri Lanka is known to be one of the highest users of fertilizers, thereby increasing the nutrient levels in wetlands, especially phosphorous and nitrates, leading to eutrophic conditions (Atapattu and Kodituwakku 2009). Excessive levels of nutrients have been reported from the Kirindi Oya area where upstream irrigation water was within the acceptable water quality standards, but the drainage and lagoon water had high values of phosphorous and ammonia, which exceeded the standards for aquatic ecosystems or aquaculture (Matsuno 1999). This also created eutrophic conditions in some parts of the lagoon (Priyankarage 2002; Priyankarage et al. 2003).The heavy use of pesticides is another major concern as these are more persistent and difficult to breakdown.

Soil erosion due to upstream agricultural practices is a concern the world over and is seen as a potential threat that will increase with the intensification of agriculture. In the Kirindi Oya study, levels of suspended solids were also found to exceed the standards for aquatic ecosystems or aquaculture (Matsuno 1999). Coastal erosion on the other hand is a much bigger problem in the region, which is brought about by altered currents and sediment loads, and can also be caused by changes in upstream coastal land uses (Atapattu and Kodituwakku 2009).

These agriculture-induced stresses have significant implications for ecosystem processes, which in turn affect the services that they can provide both to the environment and dependent communities. These conditions reduce the productivity of the wetland ecosystem and disturb the equilibrium of the system. Associated fauna and flora may be affected, the most obvious example being fisheries and water birds, while less obvious but important changes may also take place in the micro faunal communities that support the ecology of the system and the food chain (Matsuno 1999; Atapattu and Kodituwakku 2009; Falkenmark et al. 2007).

Wetland dependent communities rely on them for their income generation, for example through fisheries and tourism, as well as food, freshwater and recreation (see Table 1). The degradation of a wetland system can, therefore, have serious implications for the livelihoods of dependent communities. For example, in Kalametiya, on the southern coastline of Sri Lanka, lagoon fishermen from villages adjacent to the lagoon have revealed that conditions in the Kalametiya Lagoon have altered significantly since the early 1970s, particularly with the lagoon shrinking and becoming shallower. The changes were attributed to a combination of the development of the Uda Walawe and Kachchigal Ara irrigation scheme (1967), the subsequent creation of a permanent opening to the sea, and the building of two bunds along the banks of the Kachchigal Ara channeling all water to the sea outlet (Clemett et al. 2003; Senaratna Sellamuttu and Clemett 2003).

The fishermen attribute several impacts to these changes. The fish habitats and fishing grounds have shrunk as the lagoon has shrunk and paddy lands have replaced marsh and lagoon area. The increased inflow of fresh water and the higher velocity of the outgoing water, which has limited the exchange with seawater, have both reduced salinity. The latter has prevented the propagation of post-larvae shrimp and the fishermen cite this as the reason for the collapse of a previously thriving shrimp fishery. Another associated problem, according to the fishermen, was the influx to the lagoon of sediment carried in irrigation water running off up-stream paddy lands, which they say has reduced the depth of the lagoon (Clemett et al. 2003; Senaratna Sellamuttu and Clemett 2003; Senaratna 2007).

These changes in conditions were verified by aerial photographs of the Kalametiya Lagoon from 1956 and 1994 that show a decline in the lagoon area and the encroachment of mixed mangroves and homesteads. Studies undertaken around the lagoon have shown a decline in the number of people fishing, reaching as much as 60 % in the village of Wewegoda. Those who remain in lagoon fishing were found to be among the poorest in the area and daily incomes from lagoon fishing had declined from around Rs. 2,000 per day to just Rs. 100-150. Due to the reduction in income generation, the frequency of fishing has increased from 2-3 days per week to sometimes several times a day to generate a sufficient income (Clemett et al. 2003; Senaratna Sellamuttu and Clemett 2003; Senaratna 2007). Increased frequency of fishing can itself induce further environmental pressures.

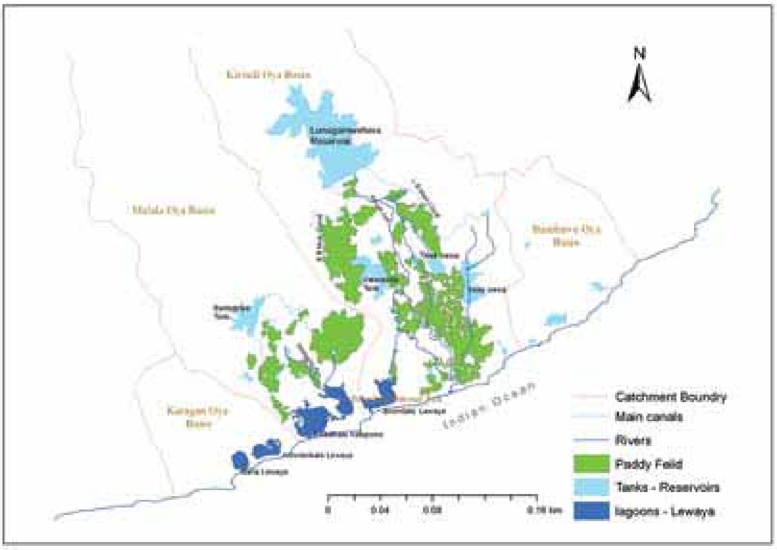
In considering the implications of agricultural activities on livelihoods, the inequities between upstream users and downstream users need to be recognized and understood. The upstream users are often not at the receiving end of the negative impacts but contribute towards them. This brings to the forefront the necessity for IWRM at river basin scale so that users and the environment benefit simultaneously to whatever extent is possible.

A Case for Adoption of Effective IWRM in Sri Lanka

The Kirindi Oya and the Bundala Wetland was selected as a case study to show the need for effective IWRM in Sri Lanka as it is a wetland of international importance and the first Ramsar site in the country. It also demonstrates both the qualitative and quantitative impacts of upstream agriculture water use. The Bundala National Park, which is located on the south coast of Sri Lanka, is made up of 6,216 ha of lowlands, including five shallow brackish water lagoons (Maha, Koholankala, Malala, Embilikala and Bundala) which cover a total surface area of 2,250 ha (see Figure 1). The Park supports important populations of water birds, elephants, crocodiles, turtles and other fauna which are reliant on the water bodies for their well-being. The lagoons are important nursery grounds for shrimp, fish and a variety of other aquatic organisms, which are an important component in the overall food cycle of the biological system (Jayawardene 1998; Rajapakse 1998; van der Hoek. 1998).

The study area is fed by surface runoff, streams and rivers, inflow from drainage channels of upstream irrigation schemes and inflow and seepage from the sea (Figure 1). Significant agricultural activities impacting on this wetland arise from the Kirindi Oya, which supports an old and new irrigation scheme with a number of ancient tanks that provide irrigation on the left and right banks, and another irrigation scheme connected to the right bank (van der Hoek. 1998). The Malala Oya and the Weligatta Ara feed directly into the Malala Lagoon and Embilikala Lagoon, which are interconnected and function as one hydrological body (Smakhtin et al. 2004).

Figure 1. Map of the Bundala National Park and surrounding catchment areas.



Source: Adapted from Matsuno et al. 1998

The main significance of Bundala is the presence of resident and migratory water birds. The biological productivity of the wetlands provides an ideal habitat for wintering for migratory birds (48 out of the 149 species of birds observed are migratory) sometimes accommodating rare species such as the black-necked stalk and flamingos. In the case of the latter, Bundala represents one of only a few sites where these birds are seen annually in Sri Lanka (Rajapakse 1998). The main characteristics of the lagoon system in Bundala wetland are summarized in Table 2.

Studies on water quality and hydrology show that the Embilikala and Malala lagoons have been affected by the Kirindi Oya Irrigation and Settlement Project (KOISP), which has reduced salinity levels and increased water levels, due to the inflow of irrigation drainage water (van der Hoek 1998; Maring and Schuurmans 2000; Kularatne 1999). Changes in the salinity levels have resulted in the decline in brackish water shrimp species, which was an economically valuable fishery, providing income to many of the surrounding communities (Matsuno et al. 1998).

Table 2. The characteristics of the lagoon system in the Bundala wetland system.

Lagoon	Characteristics	Significance/ Activities	Irrigation Influences	Impacts
Maha	Naturally formed hyper saline shallow lagoon	Feeding ground for migratory and resident water bird populations Elephant corridor Developed for salt production Cattle grazing	Unknown	
Koholankala	Hyper saline shallow lagoon (390 ha) Subject to highly varying water levels. Salinity exceeds 34 ppt during dry periods	Developed for salt production Little data available	Unknown	
Malala	Low saline lagoon (650 ha) connected to Embilikala Lagoon through small channel. Receives water through Malala Oya. Has direct link to the sea through the Malala Modera	Feeding ground for migratory and resident water bird populations Fishing Tourism	KOISP and Badagiriya Irrigation Schemes 1986 to 2009	Environmental - Drainage inflow causing salinity reduction and altering water quality and quantity. Changing assemblage and quantity of crustacean and fish species. Affecting water bird species and other fauna and flora. Socioeconomic - Prior to KOISP, about 400 families were involved in prawn fishing in both Malala and Embilkala lagoons
Embilikala	Low saline lagoon (420 ha) with no direct opening to the sea. Connected to Malala lagoon through small channel. Receives water through Weligatte Ara.	Feeding ground for migratory and resident water bird populations Fishing Tourism	KOISP and Badagiriya Irrigation Schemes 1986 to 2009	Environmental - same as Malala
Bundala	Brackish to saline lagoon (160-190 ha) with an opening to the sea. Seawater enters lagoon mainly through seepage. Parts converted for salt production	70 % is used for salt production Feeding ground for migratory and resident water bird populations Tourism Livestock grazing	None	Environmental - High grazing pressure Socioeconomic - Although traditionally an agricultural village, 90 % of the households in Bundala village depend on the Bundala saltern for their livelihood

Source: Matsuno et al. 1998; Smakhtin et al. 2004

Furthermore, studies that compared the Embilikala Lagoon and the Bundala Lagoon (which is not affected by irrigation) showed that even though both comprise the same water bird species, Embilikala is a lower quality feeding ground. The main cause of this is the input of excess freshwater, increased sediment loads and agricultural nutrients (Matsuno et al. 1998). The increased depth of the lagoons may make it difficult for birds to feed and fluctuations in water levels result in the Embilikala-Malala lagoon system regularly breaching its coastal sand barrier. This causes the system to empty into the sea almost completely within 6 to 7 days (Smakhtin et al. 2004). These artificial interventions affect the benthic fauna, mainly small crustaceans, on which the birds feed. Since Bundala National Park is a very important wintering point for migratory species, the degradation of the habitats can seriously hinder their ability to re-fuel before heading back to their breeding grounds, thus threatening the sustenance of that bird population (Mariagrazia Bellio 2009 pers com.).

Irrigated agriculture is not the only activity to impact on the lagoon. Livestock production may lead to overgrazing and eutrophication of water bodies when manure and urine enter the system. Livestock may also compete for grazing with wildlife in the park. Fuelwood collection can impact on the ecosystems around the lagoon or, if taking place upstream, on sediment loads reaching the lagoons.

To manage this system effectively, it is therefore important to understand the complex socioeconomic situation in the surrounding area. Agriculture, salt production, livestock rearing and fishing, all form part of the livelihoods of the Bundala community, which consists of approximately 170 families (Rajapakse 1998). With the hydrological changes that have taken place so far, the biggest impact felt by the community has been on the local fishing industry. Full-time lagoon fishers were forced to become part-time fishers, while others stopped fishing in the lagoon altogether. Some of these communities took up alternate livelihood activities such as shell mining and bird hunting, which often resulted in legal action being taken by the Department of Wildlife Conservation (Kularatne 1999). Another study reported that lagoon fishermen in Malala and those in associated trades, such as net makers, were badly affected by the changes in the lagoon and had been forced to diversify their livelihood strategies by undertaking agricultural labor, and lobster and deep-sea fishing. Those that continued to fish used non-sustainable fishing techniques and also increased the use of family labor, thus resulting in an overall increase in the number of fishermen using the lagoon (Kularatne 1999).

Discussion

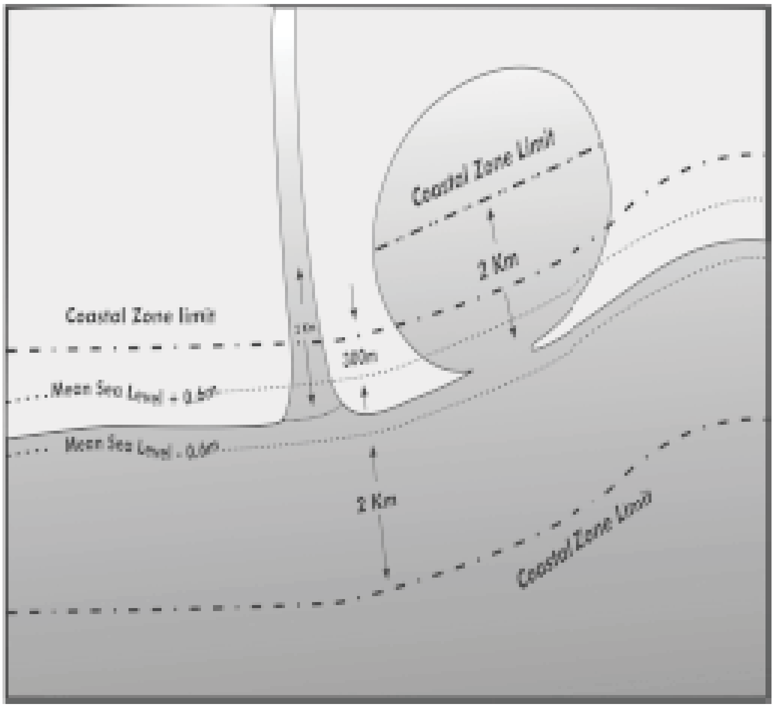
The Kirndi Oya-Bundala case study, and also Kalametiya help to illustrate the multiple impacts that could occur on downstream wetlands as a result of upstream agricultural water use when not planned within an IWRM framework. Apart from the impacts on the country's wetland biodiversity, the undermining of ecosystem services to local communities makes clear the trade-offs inherent in manipulating the hydrological regime in a river basin. Given the abundance of major and minor river systems in the country that often also include coastal wetlands such as lagoons and mangrove systems, learning from the Bundala and Kalametiya experiences should help to minimize the upstream-downstream tradeoffs (both ecological and economic) in future upstream irrigation interventions.

Further perspective can be given to these tradeoffs by considering the fact that wetlands in Sri Lanka are characterized by a rich diversity of wetland habitat types and a high number of plant and animal species. Out of the migratory birds that visit Sri Lanka, about 50 % are directly dependent on wetlands for food and shelter. More importantly, it should be recognized that approximately 32 % of the nationally threatened vertebrate species are dependent on wetland ecosystems (Kotagama and Bambaradeniya 2006). From a human development standpoint, Sri Lanka's coastal zone covers approximately 23 % of the total land area and accounts for as much as 4.6 million people or approximately 25 % of the country's population, many of whom derive direct or indirect services from wetlands for their income, food security and other aspects of well-being. Estimates show that the marine fishery provided approximately 91 % of the total fish production in Sri Lanka in 2003, of which 64 % was from coastal waters This fishery is important for local food security - in 2002, the fisheries sector including aquaculture, produced 302,890 tonnes of fish, of which 286,000 tonnes (94 %) were utilized locally, while the balance was exported. Furthermore, the fisheries sector provides direct employment to about 150,000 people, and sustenance to at least a million; while around 100,000 fishing families (nearly 450,000 people) inhabit the coastal zone. Of these, at least 30,000 people are believed to be engaged (part-time and full-time) specifically in the lagoon fishery. The marine and brackish water (mainly lagoon) fishery is also a key contributor at the macro level, contributing 2.7 % of Sri Lanka's Gross Domestic Product (GDP) in the 1998-2003 period and remains an important source of foreign exchange.

The competition for water between upstream and downstream users may be viewed as competition between two extremely productive systems, where hegemony of one over the other may not yield optimal results for the country's wetland biodiversity or its people. Adoption of IWRM principles thus offers a widely accepted planning framework for minimizing the trade-offs between the two. Perhaps most importantly, IWRM's emphasis on integrated planning challenges the hitherto sectorally segmented planning processes that have underpinned the Bundala and Kalametiya cases, as well as others. In this instance, the issue is not that responsibility for the management of wetlands, agriculture and water are dispersed among different institutions and legal frameworks, but the issue is the lack of an over-arching multi-sectoral institutional platform for bringing these sectoral objectives under a more holistic view for development.

Sri Lanka ratified the Ramsar Convention on Wetlands in 1990 and established the National Wetland Steering Committee (NWSC) in the same year. This Committee's reconstitution in 2003 to integrate plans for wetland areas and to coordinate development and conservation activities resulted in the formal adoption, in 2004, of a National Wetland Policy under the auspices of the Ministry of Environment and Natural Resources. The main objectives under this policy are to protect and conserve wetland ecosystems; prevent illegal utilization; restore and maintain biological diversity and productivity; enhance ecosystem services from wetland habitats; ensure the sustainable use of wetlands and traditional practices by local communities; and meet national commitments as a signatory to the Ramsar Convention on Wetlands. Principle 3.4 of the National Policy on Wetlands, 2004, provides formal recognition of the need to incorporate downstream impacts into the upstream development processes. While the role of the NWSC is confirmed by the National Policy on Wetlands (Section 5.2.2), it is suggested that the inter-sectoral integration envisaged through the NWSC alone will not be a sufficient institutional arrangement to engender effective planning as required by IWRM. In particular, given the central role played by a river's hydrology in the upstream-downstream relationships, planning at a river-basin scale appears to offer more opportunities to focus on basin-specific characteristics. Thus, the interplay between the basin scale and IWRM planning principles emerges as the proposed way forward. It is also interesting to note that the vertical spatial integration this calls for, runs contrary to the existing horizontal legal demarcation of the land between the coastal zone and the area landward beyond the coastal boundary as demarcated by the Coast Conservation Act (CCA), No. 57 of 1981 (Figure 2).[3]

Figure 2. The coastal zone as defined in the Coast Conservation Act.



From the perspective of coastal ecosystems and communities, it is already well documented that the definition of the coastal zone provides an inadequate geographical reach as a starting point for a truly integrated resource management strategy in Sri Lanka, particularly with respect to impacts from upstream activities. This definition envisages a mandate for the Coast Conservation Department (CCD) in a geographical area that runs parallel to the coastline, while the need under an IWRM approach is the opposite – extending influence inland and up to the northern boundaries of a river basin. This has meant that the CCD is dependent on

[3] The coastal zone is defined by the CCA as the area lying within 300 m landward of the 'Mean High Water Line', and up to 2 km seawards. Where another water body is permanently or seasonally connected to the sea, the landward limit is extended to 2 km as measured perpendicularly to the straight baseline drawn between the natural entrance points.

the co-operation of several other central and local government agencies if it is to influence decisions outside of the coastal zone. Although this function has been designated to the Coast Conservation Advisory Council (CCAC),[4] established under the CCA, its influence has been hitherto undermined by a focus on technical as opposed to political issues (Ranasinghe, pers com). While the need for specific institutional oversight for the coastal zone (as currently exists through the CCD) is not disputed, there is also a need for this jurisdiction to be meshed with a multi-institutional arrangement at the basin scale whereby the CCD and institutions with influence outside the coastal zone can 'talk' to each other within an IWRM framework and at a basin scale.

It is proposed that the case studies and supporting information presented above contributes to the case for adopting both IWRM and the basin scale as key tools for effective and equitable water management in Sri Lanka. It should be noted that some work towards developing both the tools and information towards this end is already being done, such as simulation models to determine environmental flows and valuing ecological services (Maring and Shuurmans 2000; Bakker and Matsuno 2001; Smakhtin and Priyankarage 2003; Smahktin et al. 2004), and which can be further built upon.

Conclusion

This paper emphasizes the urgent need for IWRM to be integrated effectively into the natural resources management policies of the national government. The urgency prevails due to the ecological as well as livelihoods tradeoffs inherent in manipulating a river's hydrological regime, and the fact that these are likely to increase as the demand for water intensifies. By replacing unplanned and ad-hoc water management measures, IWRM could allow the water requirements under situations of 'multiple use' to be balanced effectively as well as more equitably – water for the environment and water for human use – mainly agriculture. Given that achieving such a balance is central to sustainable development, IWRM thus emerges as a key tool for the government to optimize the developmental potential offered by both water and wetland resources. IWRM also emphasizes the necessity for practical solutions and techniques, which need to be researched and identified to ensure effective implementation that is suitable in the Sri Lankan context, and which may have to be further adapted to suit the individual river basins depending on the water uses, water resources and prevailing conditions.

[4] To be renamed as the Coast Conservation and Coastal Resource Management Advisory Council under S. 7, Draft Amendments to the Coast Conservation Act, No. 57 of 1981, L. D. O 47/99.

References

Atapattu, S. S.; Kodituwakku, D. C. 2009. Agriculture in South Asia and Its Implications on Downstream Health and Sustainability: A Review. *Agricultural Water Management* 96: 361-373.

Atapattu, S. S.; Molden, D. 2006. Achieving Food and Environmental Security: Better River Basin Management for Healthy Coastal Zones. In: *Environment and Livelihoods in Tropical Coastal Zones: Managing Agriculture-Fishery-Aquaculture Conflicts*, eds. C. T. Hoanh, T. P. Tuong, J. W. Gowing and B. Hardey. UK, CABI. pp. 293-302.

Bakker, M.; Matsuno, Y. 2001. A Framework for Valuing Ecological Services for Irrigation Water. *Irrigation and Drainage Systems* 15: 99-115.

Clemett, A.; Senaratna, S. S.; Banda, R. 2003. 'Can Coastal Zone Management in Sri Lanka Sustain Local Livelihoods and Ecosystems?' Policy Process Analysis Paper 2. Improving Policy Livelihood Relationships in South Asia. UK. Stockholm Environment Institute.

Coast Conservation Department. 1992. 'Coastal 2000: A Resource Management Strategy for Sri Lanka's Coastal Region', Volume II. Online: www.crc.uri.edu/download/SLCoast2000II.pdf

Coast Conservation Department. 2003. 'Revised Coastal Zone Management Plan Sri Lanka 2003'. Colombo, Sri Lanka: Coast Conservation Department.

Comprehensive Assessment of Water Management in Agriculture. 2007. 'Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture'. London, UK: Earthscan; Colombo, Sri Lanka: International Water Management Institute.

Convention on Wetlands. 1971. Ramsar, Iran.

Department for International Development (DFID). 2007. 'Diffuse Agricultural Pollution. Impacts and Options for Mitigation', Final Report. Prepared by Mott MacDonald in conjunction with the International Water Management Institute, Sri Lanka and Drainage Research Institute, Egypt. DFID Knowledge and Research Services Contract R8337.

Draft Amendments to the Coast Conservation Act, No. 57 of 1981, L. D. O. 47/99.

Falkenmark, M.; Finlayson, C. M.; Gordon, L. J. 2007. Agriculture, Water and Ecosystems: Avoiding the Costs of Going too Far. In: *Comprehensive Assessment of Water Management in Agriculture (2007) 'Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London, UK: Earthscan; Colombo, Sri Lanka: International Water Management Institute. pp. 233-277.

Finlayson, C. M. 2007. Irrigation versus Ecosystems: What are the Choices?' *Journal of the Australian Water Association*. August 2007. Online: http://ibcperu.nuxit.net/doc/isis/7578.pdf

Finlayson, C. M.; D'Cruz, R.; Davidson, N. 2005. MEA (Millennium Ecosystem Assessment): Ecosystem Services and Human Well-being: Wetlands and Water Synthesis. Washington, D.C.: World Resources Institute.

Giordano, M. A.; Rijsberman, F. R.; Saleth, R. M. (Eds.) 2006. 'More Crop per Drop': Revisiting a Research Paradigm. Sri Lanka: IWMI; UK. IWA Publishing. p. 273.

Government of Sri Lanka. Coast Conservation Act No. 57 of 1981.

GWP/TAC (Global Water Partnership, Technical Advisory Committee). 2000. Integrated Water Resources Management. TAC Background Paper No. 4. Stockholm: GWP.

IUCN. 2004. 'Wetland Conservation in Sri Lanka. *Proceedings of the National Symposium on Wetland Conservation and Management*, Colombo, Sri Lanka. p. 75.

Jayawadene, C. 1998. Environment in the Bundala National Park. In: *Irrigation Water Management and the Bundala National Park*, eds. Y. Matsuno, W. van der Hoek and M. Ranawake. Proceedings of the Workshop on Water Quality of the Bundala Lagoons. Sri Lanka: IWMI.

Kotagama, S. W.; Bambaradeniya, C. N. B. 2006. An Overview of the Wetlands of Sri Lanka and their Conservation Significance. In: *National Wetlands Directory of Sri Lanka*. Colombo, Sri Lanka: IUCN, Sri Lanka and CEA. pp. 7-16.

Kularatne, M. G. 1999. Fishermen Without Fish. The Effects of Productivity Decline in Lagoon Fisheries on a Fishing and Farming Community and Its use of Natural Resources: A Case Study of Malala Lagoon, Hambantota, Sri Lanka. The Netherlands: International Institute for Aerospace Survey and Earth Sciences, Enschede. p.118.

Maring, L.; Schuurmans, H. 2000. Wetland versus Irrigation: Scenario Analysis of Water Quantity and Water Quality Aspects of the Kirindi Oya Irrigation and Settlement Project and Bundala National Park using Simulation Modeling. The Netherlands: Wageningen University; Sri Lanka: IWMI. p. 48.

Matsuno, Y. 1999. Case Study in Sri Lanka: Irrigation and Drainage Water Quality and Impacts of Human Activities on the Aquatic Environment in Southeastern Part of Sri Lanka. Final Report on the Collaborative Research on the Improvement of Irrigation Operation and Management: Water Quality Investigations. Colombo, Sri Lanka: International Water Management Institute (IWMI). pp. 3-18.

Matsuno, Y.; van der Hoek, W. Ranawake, M. (Eds.) 1998. Irrigation Water Management and the Bundala National Park: *Proceedings of the Workshop on Water Quality of the Bundala Lagoons*., Colombo, Sri Lanka: International Water Management Institute (IWMI). p. 48.

Panabokke, C. R. 1998. Hydrology of KOISP and the Bundala National Park. In: *Irrigation Water Management and the Bundala National Park*, eds. Y. Matsuno, W. van der Hoek and M. Ranawake. Proceedings of the Workshop on Water Quality of the Bundala Lagoons. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Piyankarage, S. C. 2002. Assessment of Drainage Water Quality from the Kirindi Oya and the Badagiriya Irrigation Schemes and Estimation of Nitrogen and Phosphorus Loading to the Bundala Wetland', MSc. Thesis, University of Kelaniya, Kelaniya, Sri Lanka. xii, p. 123. Unpublished.

Piyankarage, S. C.; Mallawatantri, A. P.; Matsuno, Y.; Pathirana, A. S. 2003. Estimation of Nitrogen and Phosphorus Fluxes to Embilikala and Malala Lagoons in Southern Sri Lanka. In *Assessment of Material Fluxes to the Coastal Zone in South Asia and their Impacts*, ed. J. Ratnasiri. Proceedings of the APN/START/LOICZ South Asia Regional Workshop, Negombo, Sri Lanka, December 8-11, 2002. Colombo, Sri Lanka: Sri Lanka National Committee of IGBP. pp. 9-20.

Rajapakse, C. 1998. Bundala: Social and Environmental Challenges. In: *Irrigation Water Management and the Bundala National Park*, eds. Y. Matsuno, W. van der Hoek and M. Ranawake. Proceedings of the Workshop on Water Quality of the Bundala Lagoons. Colombo, Sri Lanka: International Water Management Institute (IWMI). pp. 11-19.

Senaratna, S. 2007. 'The Sustainability of Livelihood Dynamics in a Rural Coastal Community in Sri Lanka'. Doctoral thesis, Faculty of Science of the University of London. Imperial College London, UK. Unpublished.

Senaratna, S. S. 2008. Assessment of Impact of Infrastructure Development on Poverty Alleviation: The Case of the Uda Walawe Irrigation Project (Phase III). Part 4. Sustainable Livelihoods Component. Project report prepared for the Japan Bank for International Cooperation Research Institute for Development and Finance (JBIC) by the International Water Management Institute (IWMI). p. 103. Unpublished Report.

Senaratna, S. S.; Clemett, A. 2003. Fisher-Farmer Conflicts: Is There Any Chance for Compromise? A study of potential social conflict over natural resources in Kalametiya. Proceedings of the Fourth National Symposium on Poverty Research in Sri Lanka. Centre for Poverty Analysis (CEPA), the Programme to Improve Capacities for Poverty Research (IMCAP) and the Sri Lanka Association for the Advancement of Science (SLAAS).

Smakhtin, V. U.; Priyankarage, S. C. 2003. Simulation Hydrologic Reference Condition of Coastal Lagoons Affected by Irrigation Flows in Southern Sri Lanka. *Wetlands* 23: 827-834.

Smakhtin, V. U.; Priyankarage, S. C.; Boelee, E. 2004. *Simulating the hydrology of small coastal ecosystems in conditions of limited data*. IWMI Research Report 77. Colombo, Sri Lanka: International Water Management Institute (IWMI).

van der Hoek, W. 1998. IIMI and the Bundala National Park. In: *Irrigation Water Management and the Bundala National Park*, eds. Y. Matsuno, W. van der Hoek and M. Ranawake. Proceedings of the Workshop on Water Quality of the Bundala Lagoons. Colombo, Sri Lanka: International Water Management Institute (IWMI).

van Zon, J. C. J. 2004. In: *Wetland Conservation in Sri Lanka*. Proceedings of the National Symposium on Wetland Conservation and Management. Colombo, Sri Lanka: IUCN.

Environmental Flow Assessment: Recent Examples from Sri Lanka

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Abstract

Assessment and provision of Environmental Flows (EF) is important for the protection of aquatic ecosystems. EF are a set of discharges of a particular magnitude, frequency and timing that are necessary to ensure a certain range of benefits from a river. Such flows need to be scientifically determined and economically justified. Limited exposure to the concept of EF exists in developing countries. This paper gives two recent relevant example studies, which were conducted by IWMI, with foci on EF Assessment (EFA) and valuation of EF benefits in the Walawe and Menik Ganga river basins located in a semi-arid zone of southern Sri Lanka. The Walawe example illustrates the simple method for estimation of EF. The EF are approximated at two sites along the main stream of the Walawe River, which are located below the two main reservoirs. A desktop method is used, which is based on simulated, unregulated daily flow time series and their flow duration curves. The study also illustrates how the required hydrological information can be generated for the locations where EF assessment is intended - quickly and in conditions of limited observed data. The second Menik Ganga example is used as a case study to evaluate the costs and benefits of environmental water allocations. The EF components evaluated include the water needs for religious festivals, and the requirements of the Yala National Park, the Pilinnawa coastal wetland and grasslands, and the Yala Fisheries Management Area (YFMA) off the coast. Almost all estimates are based on use values of EF such as marketed goods and recreation. The paper intends to stimulate discussion and further research in the fields of EF assessment and economic valuation.

Introduction

Many of the world's rivers have been modified through storage, diversion and control structures to provide water for urban and agricultural supplies, to generate electricity and control floods. In many rivers, almost all the flows have been diverted. Flows left in the river or flowing into the sea were often seen as wasted water. This attitude is changing worldwide. Ensuring environmental water allocations (normally referred to as Environmental Flows – EF), which are essential to sustain elements of natural aquatic ecosystems and maintain ecosystem services (such as fish, flood protection and wildlife), is becoming an important trend in water resources management (see www.maweb.org). EF are a set of discharges of a particular magnitude, frequency and timing that are necessary to ensure a certain range of benefits from a river. All components of the hydrological regime have certain ecological/social significance and have to be mimicked in a modified flow regime; the EF. High flows of different frequency are important for channel maintenance, bird breeding, algae control, wetland flooding and maintenance of riparian vegetation. Moderate flows may be critical for cycling of organic matter from river banks and for fish migration, while low flows of different magnitudes are necessary for fish spawning, water quality maintenance and the use of the river by local people. Many authors now suggest that social aspects, such as human well-being, should also feature in EF (e.g., Korsgaard 2006; Meijer 2007). Balancing the requirements of the aquatic environment and other uses is becoming critical in many of the world's river basins as population and associated water demands increase.

The assessment of water requirements of freshwater-dependent ecosystems represents a major challenge due to the complexity of physical processes and interactions between the components of the ecosystems. Only limited exposure to EFA and management exists in developing countries (Tharme and Smakhtin 2003). Some obstacles include the lack of relevant expertise and legislative support, and the reluctance on the part of water resource developers to move away from past practices. Another reason is that economic benefits of EF are more difficult to quantify as their values are generally not expressed in market terms. To promote environmental water allocations, it is important to create awareness about the existing EFA methodologies and processes that should be followed, examine the economic side of EF, and illustrate the applicability of these approaches through relevant case studies in individual countries, which to date have had limited exposure to EF. The Walawe and Menik river case studies, presented below, address these issues in the specific context of Sri Lanka.

Case Study 1: Environmental Flow Assessment - Walawe Ganga

Study Area and Objective

Walawe is the largest river basin (2,442 km^2) in southern Sri Lanka and one of the three main rivers (Walawe, Kirindi and Menik) flowing south in the area, which, together with a few smaller catchments, form a group of basins known as the Ruhuna drainage area (Figure 1). A characteristic feature of the basin is two wet seasons, from the northeast and southwest monsoons, with precipitation peaks in April and November. The mean annual precipitation (MAP) is 2,050 mm with uneven spatial distribution. Despite the high precipitation, parts of the basin experience water scarcity problems during February-March and July-October almost every year.

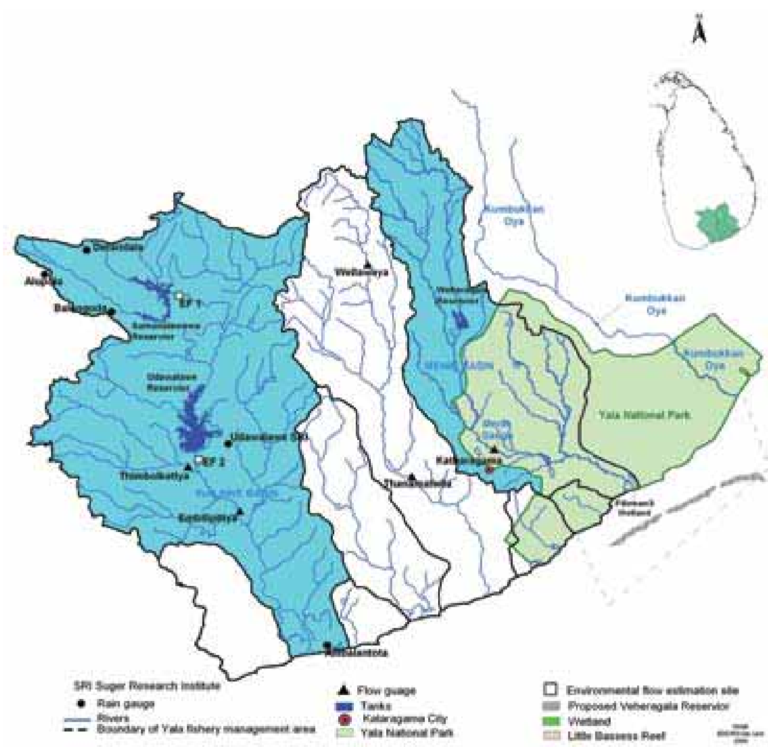
The Walawe Basin features a variety of water-related issues, from massive irrigation development to water quality and drinking water problems. Two major reservoirs for irrigation and hydropower generation are constructed on the main river (Figure1): Samanalawewa (upstream, in 1993) and Uda Walawe (middle reaches, in 1957), with a total capacity of 486 million cubic meters (MCM). Water is also transferred out of the Walawe Basin to develop irrigated agriculture in adjacent basins of the Ruhuna area. About 40 % of the catchment area is irrigated land and 20 % is under rain-fed agriculture. Expanding the irrigated area could lead to the loss of more than 5,000 ha of secondary forest, an important wildlife habitat. Human-elephant conflicts are being aggravated due to this loss of wildlife habitat, and irrigation development has had negative impacts on the aquatic environment.

There is only very limited quantitative knowledge of these impacts and no attempt has been made to quantify EF or their releases, or to ensure them. The study, therefore, aimed to undertake a quick, preliminary EFA, based primarily on hydrological information. Any EFA requires that, first, a hydrological reference condition is established, which in most of the cases means reconstructing the unregulated flow regime of a river. This reference condition may then be used to compare with and assess the impacts of land-use changes and water-resources development in a basin or to quantify the environmentally acceptable flow regime (EF).

Establishing the Hydrological Reference Conditions

The site selection for EFA was based primarily on the location of sites relative to the existing reservoirs. Site 1 (EF1) is located immediately downstream of the Samanalawewa Reservoir and Site 2 (EF2) is downstream of the Uda Walawe Reservoir (Figure 1). There are no flow observations at these sites and, hence the reference hydrological time series needs to be simulated. This simulation may be done using hydrological models or, as in this study, by observed flow data transfer techniques, known as hydrological regionalization.

Figure 1. A schematic map of Ruhuna drainage area highlighting Walawe and Menik River basins.



Only five gauges with daily and monthly unregulated flow data have been identified in the Ruhuna group of catchments. The preliminary screening and visual analyses of these time series showed that only three of these datasets are usable; as the others contain inaccurate values, have short records or other deficiencies. In addition to flow data, several observed daily rainfall datasets have been used for simulation, as described later in the paper. Although there are many rainfall stations in the basin, most of them have short records of 10 to 15 years or are located far from the sites where simulation is required and, therefore, are of little use. The rainfall stations used are shown in Figure 1.

The reference hydrology is simulated using a non-linear spatial interpolation technique based on observed rainfall and flow records (Hughes and Smakhtin 1996; Smakhtin and Masse 2000). This technique makes an intensive use of flow duration curves; a cumulative probability distribution function of flows. The components of this approach include: technique(s) to establish representative flow duration curves for different types of ungauged river catchments; and technique(s) by which the established flow duration curves may be transformed into actual continuous flow time series for any further analysis. The first part is accomplished by developing 'regional' flow duration curves. This is a relatively straightforward process of overlaying the actual flow, normalized by mean, daily discharge, 'observed' flow duration curves from available flow records (Smakhtin and Weragala 2005). Three usable observed flow datasets in the entire Ruhuna area were used to calculate regional flow duration curves. To estimate the actual (dimensional) flow duration at each EF site, it is necessary to have an estimate of the mean annual runoff (MAR) for unregulated conditions for each site. A long-term, mean daily discharge is then derived from the MAR for each site and the ordinates of the regional flow duration curve are multiplied by this discharge. The MAR values at EF1 and EF2 sites were estimated from the unregulated parts of available, monthly, time step, 'observed' flow records at the Samanalawewa gauge and Uda Walawe Reservoir, respectively (Smakhtin and Weragala 2005).

Once a flow duration curve at the EF site is established, it can be converted into actual continuous flow time series by a non-linear spatial interpolation algorithm, developed by Hughes and Smakhtin (1996). The method uses the data from one or more 'source' (gauged) sites and transfers these data through the flow duration curves to the 'destination' EF site. The main assumption of the algorithm is that flows occurring simultaneously at sites in reasonably close proximity to each other correspond to similar percentage points on their respective flow duration curves. If no suitable source flow gauge(s) with observed records can be identified in the vicinity of the destination site, more readily available rainfall records are used. In this case, both source flow time series and source flow duration curves are replaced by a rainfall-related function, reflecting the status of catchment wetness (Smakhtin and Masse 2000). The function is known as Current Precipitation Index (CPI).

$$CPIt = CPIt\text{-}1\ K + Rt \tag{1}$$

where Rt is the catchment precipitation (mm) for day t and K is the recession coefficient, which varies in a small range and has limited impact on the resultant time series.

Since no suitable flow gauges with 'unregulated' daily data in the vicinity of the EF sites are available in the Walawe Basin, rainfall data from the nearest suitable rain gauges were used. For EF1, it was the Balangoda gauge. Unfortunately, its record is limited to only 10 years, so the simulated reference flow time series was eventually also limited to the same 10-year period

(1990-2000). (The observed time series of inflows to the Samanalawewa Reservoir, which in principle represents unregulated flow conditions at the EF1 site, was even shorter and, hence the simulation for even modest extension was deemed necessary). For EF2, the source sites were those at Uda Walawe Sugar Research Institute and at Ambalantota. Both have relatively long records and were found to have similar (although not identical) temporal variability patterns. The similarity between selected rain source sites suggests that they both reflect the pattern of catchment wetness dynamics reasonably well.

Assessment of Environmental Flows

The EFA method used in this study was based on the Range of Variability Approach (RVA) developed by Richter et al. (1997). In the RVA, 32 hydrological parameters, which jointly reflect different aspects of flow variability, are estimated from a natural daily flow time series at an EF site. The RVA method suggests that in a modified (ecologically acceptable) flow regime, all 32 parameters should be maintained within the limits of their natural variability. For each parameter, a threshold of 1 standard deviation (SD) from the mean is suggested for use as a default arbitrary limit for setting EF targets in the absence of other supporting ecological information. Smakhtin and Weragala (2005) suggested that the number of parameters may be reduced to six, without detrimental effect to the overall estimation. These parameters may then be expressed as flows on the flow duration curve and, following the RVA default threshold, it can be assumed that the attained value of each selected parameter should be:

$$(\text{mean} - 1\ \text{SD}) < \text{RVA parameter} < (\text{mean} + 1\ \text{SD}) \qquad (2)$$

In most of the impacted river basins, including Walawe, it is the overall reduction of flows that is the problem. It is, therefore, the first part of (2) above that is of primary importance. This is a low-threshold condition: (mean –1 SD) < parameter.

It has been assumed that the six selected flow parameters are each exceeded the same amount of time in the modified (target) flow time series as the six original parameters in the unregulated flow time series (Table 1). The resultant ‘high-limit’ and ‘low-limit’ flow duration curves for each EF site may be estimated and plotted, as shown in Figure 2 for EF2. These flow duration curves are the summaries of EF regimes in which the selected six flow parameters are at their highest ([mean+ 1 SD]) or lowest ([mean –1 SD]) acceptable limits.

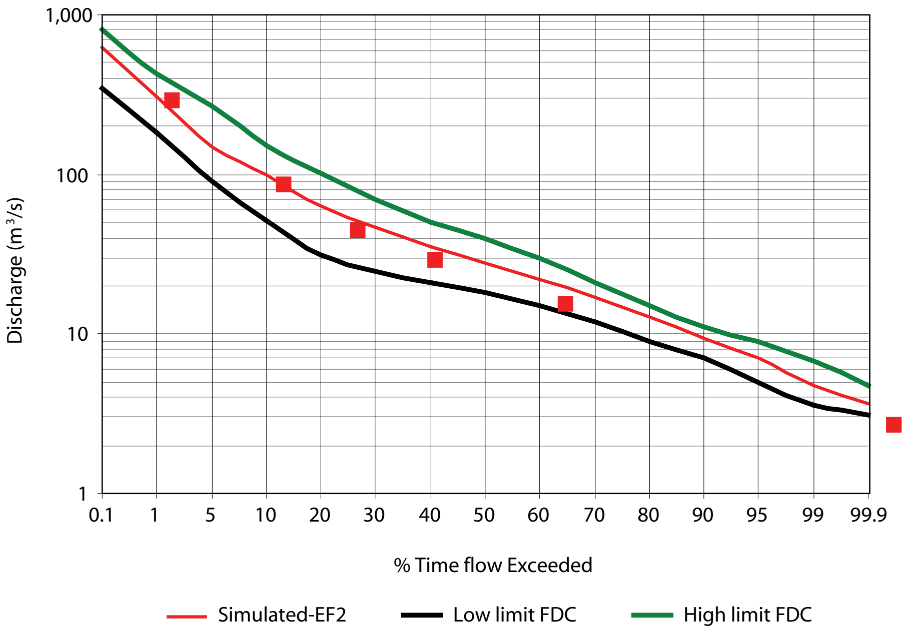
Each ‘environmental flow duration curve’ can also be converted into a complete time series of environmental flows using the same spatial interpolation approach described earlier (more details may be found in Smakhtin and Masse 2000). The interpretation of this approach needs only a minor change. The destination site now is an EF with a flow duration curve representing the environmental flow regime (e.g., Figure 2, lower curve). The source site is the same EF site but with a flow duration curve and the actual time series, representing an unregulated, originally generated flow regime. This conversion and simulation of an environmentally acceptable flow time series could be useful if the present-day flow time series downstream of the Uda Walawe reservoir was also available (they may then be compared and visualized). The authors could not locate such a time series during the course of the study. It is, however, possible to suggest that given the extensive water diversions from Uda Walawe, very little water is flowing at EF2 at all times. Therefore, it is unlikely that the established low-limit EF target is ever met.

Table 1. Selected RVA parameter analysis for site EF2.

N	Modified RVA parameter	Mean, $m^3 s^{-1}$	% time flow exceeded (for selected points only)	SD, $m^3 s^{-1}$	Low (Mean -1SD), $m^3 s^{-1}$	High (Mean + 1SD), $m^3 s^{-1}$
1	Mean: April	43.7	32.0	19.2	24.5	62.9
2	Mean: August	25.6	54.0	8.7	16.9	34.3
3	Mean: October	66.4	19.0	34.5	31.9	101.0
4	Mean: November	118.5	7.5	65.2	53.3	183.6
5	1-day minimum	5.14	98.3	1.5	3.6	6.7
6	1-day maximum	339.6	0.8	86.12	53.5	425.7

Source: Smakhtin and Weragala 2005

Figure 2. Flow duration curves illustrating unregulated flows and estimated high and low thresholds of ecologically acceptable flows for site EF2 (Uda Walawe).



Source: Smakhtin and Weragala 2005
Note: FDC: Flow duration curve
Markers show the location of the six flow parameters

Case Study 2: Costs and Benefits of Environmental Water Allocations – Menik Ganga

Study Area and Objective

The Menik Ganga Basin (1,272 km^2), is also located in the Ruhuna area (Figure 1). Its mean annual precipitation is around 1,500 mm and is received primarily during the northeast monsoon period from November to January; the dry season lasts from June to September. More than half of the catchment area is covered by forests, which extend into one of the main attractions of the area, Yala National Park (Ruhuna and Yala East), (Figure 1). The park covers 1,512 km^2, of which about 594 km^2 is within the Menik Basin. The area is rich in biodiversity and has the largest concentration of wild leopards in the world as well as supporting a significant population of elephants. The Yala coastal region has two Marine Protected Areas (MPAs) (www.mpaglobal.com): Ruhuna and Yala East. The YFMA of 450 km^2 is located within the Ruhuna MPA. In addition, the basin is known as the place of traditional religious festivals that attract a significant number of pilgrims and tourists. These features prompt the attempt to evaluate, in monetary terms, water allocations required to sustain them. The study was undertaken in the absence of any actual EF assessments, simply to explore ways of putting economic value on various, primarily non-consumptive, in-stream water uses. These uses include:

- water requirement for the Kataragama religious festival;
- requirement of the Yala National Park (primarily for the support of the large elephant population and other wildlife);
- requirement of the Pilinnawa Coastal Wetland
- requirement of the YFMA, including the needs of the Menik estuary.

Requirements for the Religious Festival at Kataragama

Each year, the 'Kataragama Festival' attracts about 100,000 people per day over a 15-day period during July and August. The main event of the festival is the water cutting ceremony held in gratitude to God Kataragama. The water cutting ceremony ideally requires about 1.2 to 1.5 meters (m) of water in the river (USAID 2005). The minimum water depth required for the festival around the Kataragama Temple has been estimated to be 0.6 m with the corresponding discharge at Kataragama gauging station of 2.0 m^3/s (Central Engineering Consultancy Bureau (CECB) 2004). However, over the past decade, the river did not carry this much flow at Kataragama during the months of the festival. Analysis of available flow records for the period of 1977-1998 shows that the long-term mean flow in the river during August, for example, is less than 0.6 m^3/s (Dissanayake and Smakhtin 2007).

Due to increasing levels of water pollution arising from low flows, water becomes unsuitable for bathing during this period and is satisfied by bowser water supply. During the 15-day festival, around 25 bowsers in total are used by the National Water Supply and Drainage Board (NWSDB), several NGOs, and the police to supply water to the migrant populations (M. G. Gunathilake, pers. comm. 2006). Therefore, the total expenditure to supply water by bowsers was used as a proxy for EF (Table 2). However, alternative bowser supplies are unlikely to provide the same satisfaction as that received from using the river.

Requirements of the Yala National Park

The Yala National Park requires water during the dry season to sustain its aquatic and terrestrial flora and fauna. However, according to the Department of Wildlife Conservation (DWLC), the stretches of the Menik Ganga that pass through the Yala National Park are completely dry throughout the months of July, August, and September (USAID 2005). Analysis of observed flow records at Kataragama suggests that, on average, the Menik Ganga is dry for about 20% of the year (Dissanayake and Smakhtin 2007). The additional allowance that the DWLC spends to cope with the water shortages (B. V. R. Jayaratne, pers. comm. 2006) during the three dry months can be taken as a proxy for the benefits of EF to the Yala National Park (Table 2). However, the actual benefits to the park are much greater than this proxy value.

The water and fodder requirements of elephants are treated as part of the EF in the Menik Ganga. The DWLC suggests a maximum of 200 elephants are living in the Menik Ganga portion of the Park (594 km^2). The maximum daily requirement for drinking and for the general hygiene for 200 elephants is relatively minor. However, the actual flow of water in a river has to be higher for an elephant to access it. To ensure the long-term survival of this elephant population, it is important to maintain the vegetation in the National Park during the rainless season, by ensuring some flow in the river and thus some healthy riparian vegetation around it.

The value of crop damage, compensation paid for damage and the value of the human elephant conflict (HEC) mitigation measures in Yala in the dry season (Table 2), could be used as proxy values for benefits derived from keeping the elephants in the park by maintaining EF in the river. During the dry season, the elephants in Yala migrate to other areas in search of fodder and water. The effects of these migrations are the destruction of property by elephants and the loss of human and elephant lives. However, data on the exact number of families affected by elephant migration, and whether they are affected by the Yala elephants specifically, are not available. These losses, therefore, cannot be quantified at present without introducing great uncertainty. Considering the attention given to elephant protection in Sri Lanka and the world, the expenditure for HEC mitigation used here is likely to be an underestimate of the benefits of EF.

An approximate value of benefits from environmental water allocation could be derived from the fact that the Yala National Park is closed from September to mid-October due to a lack of water. It is assumed that willingness to pay to visit the park depends on the condition that water is available and, hence the park is open. The loss in revenue from tourism over 1.5 months could be taken as a proxy for the value of the benefits of maintaining EF in the Menik Ganga during the rainless season (Table 2). However, the cost of entry to the park is only part of all costs associated with traveling to the park and, therefore, it underestimates the costs actually incurred. It has been estimated that the recreational value of the park in Sri Lankan Rupees is 250/ha/year (cited in CECB, 2004). The forgone recreational value in 1.5 months was estimated by inflating this average value to obtain the price from April 2006 to the time of the study, which was calculated to be US$4.35, and by multiplying this with the area of the park. The forgone recreational value in 1.5 months is, therefore, US$82,215 (Table 2).

Requirements of the Pilinnawa Wetland

The Pilinnawa Wetland (Figure 1) is considered an important site for waterfowl and a variety of other fauna, including elephants. Water required for wetland flooding was evaluated by the Central Engineering Consultancy Bureau (CECB 2004). A discharge of 250 m^3/s is required to ensure the stable inflow of water into the wetland. Hence, a release through the Weheragala Reservoir of 300 m^3/s for a period of 3 hours once every 2 years is deemed necessary to ensure a minimum flow rate of 250 m^3/s for at least 45 minutes at Pilinnawa and to flood the wetland. However, the flooding requirement of the grassland area had not been considered in this calculation. These estimates have not been verified through any EFA. Therefore, these estimates will need to be revised in the future, taking into account water requirements for breeding and feeding of birds and fish, and for the maintenance of wetland vegetation.

A Benefit Transfer (BT) done for the open water and marshy area of Pilinnawa (1.0 km^2), using the land cover as a proxy estimate, gave the total value of Pilinnawa as US$13,400 (Table 2). (A site-specific primary valuation in the future would give a more realistic estimate, which could be used as a proxy estimate of the benefits of EF).With the average value transfer from Millennium Ecosystem Assessment (MEA), the total value of Pilinnawa is US$315,100, which is likely to be a gross over-estimation. The CECB (2004) has mentioned that the grassland will be adversely affected by the proposed development at Weheragala. There are no value estimates to be found for grasslands in Sri Lanka. Using the global average unit value for grasslands and land cover as a proxy measure, the total economic value of the grassland is around US$134,560 per annum, which is probably an over-estimation. A future site-specific ecosystem valuation based on the grazing benefits would give a more realistic value of the grassland, which could be used as a proxy estimate of the EF benefits.

Table 2. A summary of EF components in the Menik Ganga and the estimates of their benefits.

EF Component	EF Estimate[1]	Volume	Evaluation method	EF Benefits (US$)	Comment
Kataragama Religious Festival	2 m^3/s	63 MCM	Total expenditure of bowser supply (Avoidance cost as a proxy)	12,375	Underestimate as satisfaction of pilgrims is not included
Yala National Park	2 m^3/s	63 MCM	Additional DWLC Expenditure in the dry season as a proxy (Avoidance Cost as a proxy)	1,470	Underestimate as this expenditure cannot eliminate the water shortage problem to the park completely
		51m^3/day (elephants' drinking water)	DWLC Expenditure for HEC mitigation in the dry season as a proxy	1,960	The EF estimate does not include the water need for fodder. The benefit estimate is much greater than HEC mitigation expenditure
		63 MCM	Foregone Tourism Revenue as a proxy	66,948	EF benefit estimate is an underestimate
		63 MCM	Foregone Recreational Value as a proxy	82,215	Based on estimate cited in CECB (2004)
Pilinnawa Wetland	250 (m^3/s) for 45 minutes every 2 years	3.7 MCM	BT land cover as a proxy	13,400	
			BT land cover as a proxy	315,100	
Pallassa (grassland)	NA	>3.7 MCM	BT land cover as a proxy	134,560	
YFMA	NA	NA	40 % of the Export value of lobster catch as a proxy (Market Price Method)	93,610	The relationship between the flow and the potential lobster catch is not established
			40 % of the Income of chank fishermen as a proxy (Market Price Method)	17,664	The relationship between the flow and the potential chank catch is not established

Source: Dissanayake and Smakhtin 2007

Notes: [1]CECB (2004) EF estimates are used; NA – Not Available; BT – Benefit Transfer; DWLC – Department of Wildlife Conservation

Requirements of the Yala Marine Protected Area and the Yala Fisheries Management Area

The YFMA is traditionally known as a good fishing ground for both edible and ornamental fish. Protected animals such as turtles, dolphins and whales are also frequently sighted. The Little Basses (coral) Reef has been identified as a highly environmentally sensitive area (NARA 2002). Freshwater has an important influence in the estuarine and in close offshore marine environments and the influence of river flow can extend into coral reef systems over 70 km offshore (Robins et al. 2005). Therefore, impact on coastal fish catches should be weighed against the economic benefits of water uses upstream. Saltwater intrusion, due to the tidal effects during the dry season in the Menik Ganga, extends approximately 7 km upstream from the mouth of the river (E. Wilson pers. comm. 2006), which could contaminate the groundwater. Reduced river flows and altered flow patterns may lead to deterioration of the water quality. The benefits of freshwater inflow from the Menik Ganga to the MPA and the river mouth should, therefore, be taken into account when assessing the costs and benefits of the EF.

There are about 40-50 fishing families who depend solely on the YFMA mainly targeting lobster, chank and skate. The estimates derived for the total export value of lobsters and the total income of the chank divers could be summed up and taken as a proxy measure for the benefits of EF to the MPA. It is assumed here that the current fish catch in the YFMA could be maintained by the total amount of EF that reaches the mouths of the main rivers flowing into the YFMA. Further research is necessary to quantify the relationships between freshwater inflow to the YFMA and fish catches. Another issue to consider is that, in addition to the water from the Menik Ganga, the Kumbukkan Oya, which is the neighboring river basin to the east of the Menik Ganga, bordering Ruhuna (Figure 1), also discharges a considerable quantity of freshwater (on average 472 MCM per annum) to the YFMA (Dharmasena 2005). Therefore, Menik Ganga freshwater flow (347 MCM) only contributes approximately 40 % of the benefits derived from the YFMA. Consequently, the benefits derived from EF in the Menik Ganga are estimated to be 40 % of the above values for lobster and chank fisheries, as given in Table 2.

Conclusions

The paper aimed to illustrate example tools and approaches which could: (i) provide hydrological data for EFA; (ii) perform quick preliminary EFA in conditions of limited data; and (iii) put an economic value on EF. All of these approaches are mostly ‘work in progress’, they have not been used in Sri Lanka before, and therefore are presented here primarily for the reasons of promoting the concepts of EF, creating awareness of the need to consider EF allocations as a legitimate use of water and stimulating discussion around these topics in the country.

Hydrological information (natural flow time series) is necessary regardless of the type of EFA method chosen and can also be used for different engineering applications. The hydrology-based desktop EFA method illustrated in this study and simplified without losing its major concept, which is the preservation of flow variability, is an example of the first step towards evaluating EF. Such hydrology-based desktop methods, developed elsewhere, need to be re-calibrated and tested in different physiographic environments (such as monsoon driven flow regimes of Sri Lanka) before they can be reliably applied. Hence, there is a need to further develop, modify and test existing methods in specific river basins.

The economic benefits valued in this study and attributed to environmental water allocations are significant when compared to the total value of the dry season paddy yield of US$567,000 (CECB 2004), which is a value likely to be exceeded by the total value of EF (if non-use values and other components of EF are included). The suggestions that were examined with regard to putting an economic value on various environmental water uses were also the 'first cut' and are quite simple approaches. They allow awareness to be raised regarding the potential and real damage that may be or is already occurring, due to neglecting the needs of the aquatic environment.

Acknowledgements

This study is part of the research project 'Environmental Flows: Theory and Practice', which is supported by the core funds of IWMI. We thank Mr. M. G. Gunathilake, District Engineer, National Water Supply and Drainage Board, Kataragama, Sri Lanka; Mr. Wasantha Ratnayake, Director, and Mr. Edmund Wilson, Deputy Director, Elephant Conservation, Department of Wildlife Conservation, Colombo, Sri Lanka; Mr. B. V. R. Jayaratne, Divisional Assistant Director, Department of Wildlife Conservation, Kataragama, Sri Lanka; Mr. Buddhika Vithana and Mr. Weragala, Department of Wildlife Conservation, Yala National Park, Sri Lanka; Ms. P. P. Dias, Head, Division of Hydrology, Department of Irrigation, Colombo, Sri Lanka; Dr. Champa Amarasiri, Head, Marine Biological Resources Division, National Aquatic Resources Research and Development Agency, Colombo, Sri Lanka; Mr. Anil Premaratne, Deputy Director-Planning, Coast Conservation Department, Colombo, Sri Lanka; Staff, Fisheries Statistics Division, Ministry of Fisheries and Aquatic Resources, Colombo, Sri Lanka, for the provision of useful information and insights during the course of this study.

References

CECB (Central Engineering Consultancy Bureau). 2002. Environmental Impact Assessment Report: Proposed Water Resources Development Works Across Menik Ganga at Kuda Gal Amuna. Kuda Gal Amuna Project, Sri Lanka, Department of Irrigation. p.137.

CECB (Central Engineering Consultancy Bureau). 2004. Environmental Impact Assessment Report: Quality Enhancement of Lunugamwehera National Park in the Menik Ganga and Kirindi Oya Basin by Harnessing the Development of Water Resources of Menik Ganga, Weheragala Reservoir Project, Sri Lanka Department of Irrigation. p. 290.

Dharmasena, G. T. 2005. Proposed Menik Ganga Reservoir: A Sensible Step. *Daily News*, April 28, 2005 (Sri Lanka).

Dissanayake, P.; Smakhtin, V. 2007. *Environmental and social values of river water: Examples from the Menik Ganga, Sri Lanka*. Working Paper 121. Colombo, Sri Lanka: International Water Management Institute. p.15.

Hughes, D. A.; Smakhtin, V. U. 1996. Daily Flow Time Series Patching or Extension: A Spatial Interpolation Approach Based on Flow Duration Curves. *Journal of Hydrological Sciences* 41 (6): 851 – 871.

Korsgaard, L. 2006. Environmental Flows in Integrated Water Resources Management: Linking Flows, Services and Values. Lyngby, Denmark: Institute of Environment and Resources, Technical University of Denmark. p. 60.

Meijer, K. S. 2007. Human Well-being Values of Environmental Flows: Enhancing Social Equity in Integrated Water Resources Management, Delft, the Netherlands: IOS Press. p.195.

NARA (National Aquatic Resources Research and Development Agency). 2002. Draft Report on Socioeconomic and Ecological Profile of the Fishery Management Area off Yala National Park. p. 35.

Richter, B. D.; Baumgartner, J. V.; Wigington, R.; Braun, D. P. 1997. How Much Water Does a River Need? *Freshwater Biology* 37: 231-249.

Robins, B. J.; Halliday, I. A.; Staunton-Smith, J.; Mayer, D. G.; Sellin, M. J. 2005. Freshwater-flow Requirements of Estuarine Fisheries in Tropical Australia: A Review of the State of Knowledge and Application of a Suggested Approach. *Marine and Freshwater Research* 56 (3): 343-360.

Smakhtin, V. U.; Masse, B. 2000. Continuous Daily Hydrograph Simulation Using Duration Curves of a Precipitation Index. *Hydrological Processes* 14: 1083-1100.

Smakhtin, V.; Weragala, N. 2005. *An assessment of hydrology and environmental flows in the Walawe river basin, Sri Lanka*. Working Paper 103. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Tharme, R. E.; Smakhtin, V. U. 2003. Environmental Flow Assessment in Asia: Capitalizing on Existing Momentum. In: *Proceedings of the First Southeast Asia Water Forum, November (2003), Chiang Mai, Thailand*. Bangkok, Thailand: Thailand Water Resources Association. Volume 2: pp. 301-313.

USAID (United States Agency for International Development). 2005. Managing Conflict in Watersheds of Sri Lanka. Final Report. p. 58.

Non-user Benefits Emanating from Enhanced Water Flow to the Yala Protected Area Complex

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Abstract

Water is a multiple use resource. Increasing scarcity and competition from various sectors is an important dimension to be considered in its management. Understanding the value of water to different water uses is, therefore, necessary to assist decision-making in water allocation among sectors. Although water used in agriculture can be valued using production function approaches, such direct valuation methods are not available for the environmental uses of water. This paper uses non-market valuation methods to estimate the economic value of a committed flow through a unique ecosystem, the Yala Protected Area Complex (YPC).

The Yala Protected Area Complex is an important wildlife refuge situated in south-eastern Sri Lanka. Its large land extent, undisturbed nature, and abundance and diversity of fauna contribute to its uniqueness. The fact that the YPC is also the most visited national park in Sri Lanka is partially a result of this uniqueness. However, maintenance of the park's ecosystem depends on the flow of the Menik Ganga. This flow is regulated by the Veheragala Reservoir Project, and there is now discussion of reducing flow into the park by about half of the current level. The proposed plan ensures dry season flow into the YPC and, therefore, has been deemed acceptable. However, there is a possibility that farmers will demand further water releases during the dry season which could in turn endanger the planned downstream water releases. So there is a potential trade-off between environmental and irrigation uses of water.

A willingness to pay (WTP) survey was conducted in ten districts in Sri Lanka during the fourth quarter of 2008 to estimate the WTP of the general population of the country towards maintaining this important environmental resource. In the hypothetical market presented, participants were told of the need for financial contributions from the general public to ensure the release of a minimum downstream flow commitment of 50 MCM. Participants were also informed of how this flow would enhance the ecosystem of the YPC. A single bound dichotomous choice contingent valuation approach was used as the elicitation format. Non-obligatory voluntary contributions were solicited towards a trust fund that could be used to ensure release of the required quantity of water downstream during dry months.

According to the results of a binary logistic regression, income, age, and religious attachments are important factors affecting the decision to contribute to environmental flow maintenance to the YPC. Sixty-five percent of respondents were willing to pay something to ensure the maintenance of an adequate environmental flow in the YPC. The estimated mean WTP for water releases to enhance the YPC is Sri Lankan Rupees (SLR) 435 per year. Over the requested payment horizon of 10 years, the present value of aggregate WTP from the Sri Lankan population to enhance the ecosystem of the YPC is SLR 12 billion. This quantity greatly surpasses the present value of net benefits from rice farming estimated at SLR 0.64 billion, which would be generated if the same quantity of water was used for irrigation for 10 years (assuming current prices and input intensities). Thus, there is a clear opportunity for national welfare gain by ensuring adequate flow in YPC.

Introduction

Water is a multi-purpose natural resource and is the foundation of life and civilizations. The natural availability of water in an area is governed by hydrological factors. Throughout history, humans have altered the natural patterns of spatial and temporal availability of water for their benefit. The idea of treating water as an economic good and subsequently using the concept of marginal value in water allocation decisions is on the frontline of developmental thinking today. Optimum inter-sector water allocation requires knowledge of the marginal values of water by different sectors and uses.

Valuation of water is a complex task. Different sectors require different valuation approaches and these measures should be aggregated at the end. Water valuation falls within the broader area of environmental valuation, which is built on the notion that markets do not exist for some goods and services. Although development agencies emphasize water as an economic good, (World Commission on Water for the Twenty-first Century, 2000; ICWE 1992), the applicability of this concept, especially in developing countries, has been questioned (Davis 2005; Theesfeld 2004). Furthermore, incorporating environmental values in water allocation decisions is now being emphasized by recognizing that substantial stream-flows are necessary for maintaining eco-systems (Whiting 2002).

As water allocation rules are increasingly using economic values as an allocation criterion, it is important to incorporate the values generated by all potential water uses within a total economic value framework. Non-inclusion of some potential values would lead to undervaluation of water with the potential danger of depriving some users through under allocations and irreversible policy decisions.

Wildlife and park reserves are an important component of land use in many countries. Although the general public has limited use of these reserves, the greater need for the establishment of these reserves is for habitat conservation and biodiversity. This research uses non-market valuation methods to estimate the value of water flow in a forest ecosystem in southeastern Sri Lanka, namely the Yala Protected Area Complex (YPC). Valuation of the resource was conducted through a willingness to pay (WTP) survey using a nationwide sample. This paper first describes the YPC and the proposed water allocation followed by a discussion of the theoretical basis of non-market valuation. This is followed by a description of the research procedures, the results, and a discussion of the results.

The Yala Protected Area Complex

The Yala Protected Area Complex (YPC) is an aggregation of protected areas extending northeast from the southeastern shoreline of Sri Lanka. It is located 280 km from Colombo (the capital) and lies in the Hambantota, Monaragala and Ampara administrative districts. The YPC is administered by the Department of Wildlife Conservation and has a total area of 144,934 ha. The complex and adjoining protected areas form the largest contiguous protected area in the country covering 171,000 ha. The YPC is rich in wildlife, including Asian elephants, leopards, sloth bears (the only bear species found in Sri Lanka), and the endangered marsh and estuarine crocodiles. Two-hundred and eighty species of plants are found in the area. The area is home to over 280 bird species and was once a popular birding area. The YPC provides large, contiguous areas of undisturbed habitat needed by large animals, such as the elephants and crocodiles found there. This makes the YPC an important undisturbed eco-system of national and global interest.

The YPC has been the most visited national park in Sri Lanka in recent years. Most visitors are domestic tourists whose primary destination is the nearby Kataragama Sacred City. Although Yala is heavily visited, it remains an important wildlife refuge because only 10 % of the total area is open to the public. This and limited access portals, in general, underlie the area's conservation value.

Twelve rivers with a cumulative watershed area of 3,087 km^2 flow through or border the YPC. However, about 80 % of the total water discharge is contributed by the Menik Ganga and Kumbukkan Oya rivers. The project of interest in this analysis is the Veheragala Diversion Project, implemented by the Sri Lanka Department of Irrigation. The project was designed to change the current flow regime of the Menik River through the construction of a 75 MCM (million cubic meters) storage reservoir. The total expected annual diversion to the Kirindi Oya basin is 75 MCM. The structure of the current flow of the Menik River is highly seasonal. The estimated water yield from the watershed above the dam site is 153 MCM, about 44 % of the river's annual runoff. Implementation of the project will result in a 50 % reduction of the downstream flow from the dam site.

According to the proposed water allocation plan of the Veheragala Project (Table 1) the seasonal nature of the flow will be altered. The committed downstream flow rate of 1.5 m^3s^{-1} is greater than the average flow rate during the dry season. About 47 % of the current water volume is available for use within the basin. Two major tributaries of the Menik Ganga, the Hangune Ara and the Darage Ara, join the river downstream of the reservoir site. These and other small tributaries collectively contribute to a total of 193 MCM of discharge downstream of the proposed dam site and are not affected by the project. Therefore, the resultant flow changes can be considered as beneficial to the YPC ecosystem because the regulated release of downstream water will ensure continued water flow in the river, thus eliminating the current dry periods. Large-scale water releases to flood wetlands near the estuary of the river are also planned.

Table 1. Annual water balance at Veheragala after the project.

	Component	Volume (MCM)
	Inflow	153.7
Commitments		
(A)	Downstream flow	47.3
(B)	Dead storage	6.5
	Total in Basin (A + B)	53.8
(C)	Diversion to Kirindi Oya	75.0
	Total (A + B + C)	128.8
(D)	Non committed available for In basin use	24.9
Total downstream flow	(A + B)	72..2

The objective of ecosystem enhancement will be realized only if the water is issued during the dry season. However, these releases are required during the peak water demand for agriculture. Since water is stored in the reservoir for release during forthcoming months, it is possible for groups, primarily farmers, to press for the release of water to their fields. If this occurs the situation will be worsened as no return flows will be available downstream of the Menik River. The volume of the expected downstream release of 50 MCM is equal to that needed to irrigate about 1,500 ha of rice during both cultivation seasons. This generates average annual net benefits of SLR 103,552 per ha, based on current input intensities and prices.

We do not expect a drastic change in the regulations of the protected area, and these areas will be administered for wildlife conservation purposes. Therefore, flow enhancement will ensure the existence of the YPC and benefit the wildlife habitat. Based on this scenario, the objective of the WTP survey was to estimate the WTP of the general population of Sri Lanka to maintain the YPC ecosystem through assured water releases to the YPC during the dry season. The non-market good here is the quality of the environment. We expect an improvement of environmental quality from the current (poor) state before the regulated flow, to the expected (good) state after the regulated new flow regime if water is allocated based on environmental concerns.

Theoretical Basis for Environmental Valuation

The concept of total economic value is used in valuing resources that generate multiple benefits. Values arise from both use and non-use values. As described by Freeman (2003), valuing non-market goods is based on the welfare measures for a utility-maximizing consumer.

Non-market valuation techniques are classified into two broad classes: revealed preference (RP) methods and stated preference (SP) methods. Revealed preference methods use the market behavior of an observable good or service related to the environmental amenities, while SP methods are based on hypothetical markets. Values associated with environmental quality may be expressed through market behavior. The Contingent Valuation (CV) Method is the most widely used of several SP methods and is extensively used in valuing recreational benefits and quality of water. The use of SP methods has its own niche as it can hypothetically create markets that are otherwise non-existent, including non-use values.

We used single bound dichotomous choice format in eliciting responses. Non-obligatory, specific voluntary contribution mechanisms (VCM) were considered an appropriate payment vehicle because charitable contributions of various sorts are widespread in Sri Lankan society, but tax collection is a relatively weak institution. In an evaluation of the Sinharaja Biosphere Reserve, Ekanayake and Abeygunawardena (1993) used payment to a conservation club for estimating total economic value. More recently, Bandara and Tisdell (2005) reported that VCM was the method of payment preferred by respondents for a hypothetical elephant conservation program in Sri Lanka. Elicited responses were used to calculate WTP, estimating a non-parametric survivor function (NSF). A binary logistic regression model was estimated in order to understand the determinants of willingness to contribute to the improvement of the YPC.

Survey Design and Implementation

A CV survey was conducted during the last quarter of 2008 in ten districts randomly selected from a list of 18 administrative districts in Sri Lanka. Of the 25 administrative districts in Sri Lanka, 7 districts from the northern and eastern provinces were not included in the sample selection due to the logistical difficulties of conducting socioeconomic surveys). According to the most recent National Census of Population and Housing conducted in 2001 (Department of Census and Statistics 2004), the cumulative population of the districts surveyed accounted for 86 % of Sri Lanka's total population. We used a multi-stage random sampling procedure to select respondents. In the first stage, the 10 survey districts were selected using the Probability Proportionate to Size (PPS) sampling method. The use of 10 districts was based on the expectation of generating more than 500 valid responses, the minimum to carry out a valid dichotomous choice CV survey. Two divisional secretary areas from each selected district were randomly selected during the second stage, while one village from each selected DS division was selected in the third stage. Respondent households were randomly selected at the final stage.

The 10 districts that were selected were a good representation of the regional variations within the country. The sample contained approximately 20 % urban and 80 % rural respondents, equal to the urban/rural population proportions in Sri Lanka. However, we did not differentiate between the WTP of urban and rural responses at this stage as the sub-samples in our study were not large enough to generate separate WTP values.

A one-page insert describing the significance of the YPC and the proposed changes to the water flow regime of the Menik Ganga River was included in the questionnaires. In order to reduce the potential influence on WTP from expected future uses, we emphasized that the area through which the river flows is not open to the public. The hypothetical scenario was constructed to show the improvements to the downstream ecosystem if water is released to the park as scheduled. The expected enhancement of the quality of the downstream eco-system was depicted using pictures showing differences in the state of the environment with and without water flow as described. Change in the flow pattern, including the quantity of water (expressed as the quantity of water needed to irrigate the expected extent of rice land) was mentioned. Monetary contributions from the general public were explained to be needed to protect downstream releases of water from possible additional demands from the agriculture sector.

Using single bounded dichotomous choice elicitation format, respondents were asked whether they would pay for a period of 10 years, an annual membership fee to the Yala Environment Protection Organization (YEPO) the amount of which was equal to the presented bid value. The YEPO was modeled as a not-for-profit organization with democratic member control. News of its activities and programs were expected to be disseminated to members through a newsletter. Bid values selected were, 100, 300, 500, 700, and 900 SLR. These values were within the range of actual payments made by Sri Lankans for memberships in social and professional organizations. Each bid value was randomly assigned to one-fifth of the sample households in each survey village. Responses were analyzed using the non-parametric survivor function approach. A follow-up question asking whether they are willing to pay for the same purpose, any other positive contribution was presented to respondents who answered “No” to the WTP question.

The standard procedure for drop-off and pick-up surveys was followed. Our survey is the first-ever documented socioeconomic survey of this type in Sri Lanka. The survey was completed by the principal decision-maker of the household, and completed questionnaires were collected after 2 weeks.

Standard demographic and socioeconomic information and information on possible determinants of the WTP decisions were also collected (Table 2). Distance from the main entrance of the YPC to the center of the respondents’ villages was measured using 1:50,000 topographic maps.

Table 2. Independent variables in the Binary Logistic Regression.

Variable Name	Description	Measure
edulvl	Number of years of education	Years of education
hhhage	Age of the Household Head	Years
graduate	Higher education status of Household Head	1, if the household head had a college degree 0, otherwise
inccls01	Annual Household income class	1, if income is less than SLR 75,000 0, otherwise
inccls02	Annual Household income class	1, if income is between SLR 75,000 and 120,000 0, otherwise
inccls03	Annual Household income class	1, if income is between SLR 120,000 and 240,000 0, otherwise
inccls04	Annual Household income class	1, if income is between SLR 240,000 and 360,000 0, otherwise
inccls05	Annual Household income class	1, if income is over SLR 360,000 0, otherwise (Reference Category)
ofchloco	Office holder in local organizations	1, if office holder 0, otherwise
assets	Asset index	Index of household assets and housing quality
religious	A proxy variable to measure close association with religion	1, if the household contributes regular donations to religious institutions 0, otherwise
distypc	Road distance from main entrance of YPC to the village	km

(continued)

Table 2. Independent variables in the Binary Logistic Regression. (continued)

urban	Sector of residence	1, if respondent's residence is located in urban area 0, otherwise
heard	Level of awareness	1, if respondent had previous awareness of YPC 0, otherwise
vistypc	Visitor status	1, if respondent has visited YPC 0, otherwise

Results and Discussion

Calculation of WTP

Calculated values of the non-parametric survival function are presented in Table 3. The estimated mean WTP for enhancement of the YPC in the sample is SLR 435 per annum per household, with a 95 % confidence interval between SLR 401 and SLR 467. Estimated mean household WTP was aggregated for the whole population of survey districts using mid-year population

Table 3. Estimated point estimates of non-parametric survival function (n = 531).

Bid Value (SLR)	Number of respondents (Nj)	Number of response		Point estimate of non-parametric survival function
		Yes (nj)	No (Nj - nj)	
100.00	107	82	25	0.77
300.00	109	59	50	0.54
500.00	106	51	55	0.48
700.00	104	43	61	0.44
900.00	105	37	68	0.35
Total	531	272	259	

in Sri Lanka in 2008 (Central Bank of Sri Lanka 2009). The average household size reported by the Sri Lanka Household Income and Expenditure Survey 2006/07 is 4.1 persons. Thus, the total number of households in the survey districts is 4,422,927, and there are 503,171 households in the excluded districts from the northern and eastern provinces. We estimated an aggregate WTP of SLR 1,920.8 million per annum for the survey districts. As payments will occur for 10 years, the net present value of the WTP stream, using a 12 % discount rate, is SLR 10.8 billion.

We used WTP values from the survey districts to calculate WTP for the rest of Sri Lanka assuming that residents in excluded districts would have the same average WTP and that household size is as in the survey districts. The cumulative WTP to enhance the ecosystem of the YPC is estimated to be SLR 12 billion for the entire Sri Lankan population. The net present value of incremental net benefits, arising if the quantity of water committed to downstream use is diverted to the adjoining Kirindi Oya Basin and used to grow rice, would be SLR 0.64 billion at current input intensities and factor/output prices. This reveals that the estimated WTP for the YPC from the general population of Sri Lanka is several times higher. This generates important policy implications as welfare gains from a larger population should be considered an important input when deciding water allocations at the Veheragala Reservoir Site.

Factors Affecting the Decision to Contribute for Conservation

Descriptive statistics for the explanatory variables used in the binary logistic regression are presented in Table 4. Sixty-five percent of respondents agreed to support the YEPO by a positive annual membership contribution. On average, respondents had 12 years of education and 19 % of them had a university degree. The age of household heads ranged from 20 to 88 years with an average of 46 years. Eighty-eight percent of household heads were males. Sixty-five percent of the surveyed households indicated that they contributed to a Buddhist temple. It was hypothesized that holding an office in a village organization would positively influence attitudes on environmental protection; in this case 26.2 % of the respondents were office holders in a non-political or social community level organization.

Table 4. Descriptives of explanatory variables in Binary Logistic Regression (n = 531).

Variable Name	Mean	SD
edulvl	12.56	(2.69)
hhhage	46.08	(11.5)
graduate	18.8%	
inccls01	14.1%	
inccls02	16.6%	
inccls03	36.0%	
inccls04	15.4%	
inccls05	17.9%	
religious	65.5%	
heard	97.9%	
vistypc	45.4%	
urban	20.2%	
ofchloco	26.2%	

Source: Survey data 2008

According to the results of the binary logistic regression (Table 5), older household heads were less likely to contribute to the YEPO. However, this estimate is statistically insignificant.

Table 5. Parameter estimates for Binary Logistic Regression.

Variable Name	Parameter Estimate	Significance	Significant at	Exp(β)
edulvl	-0.08758	0.123	ns	0.9161
hhhage	-0.01435	0.102	ns	0.9858
distyala	0.001746	0.241	ns	1.0017
inccls01	-0.3826	0.320	ns	0.6821
inccls02	0.200851	0.554	ns	1.2224
inccls03	0.661026	0.033	++	1.9368
inccls04	0.420969	0.233	ns	1.5234
urban	0.354011	0.174	ns	1.4248
religious	1.081865	0.000	+++	2.9502
graduate	1.43029	0.000	+++	4.1799
ofchloco	0.352732	0.136	ns	1.4229
vistypc	-0.24853	0.220	ns	0.7799
Constant	0.813202	0.421	ns	2.2551

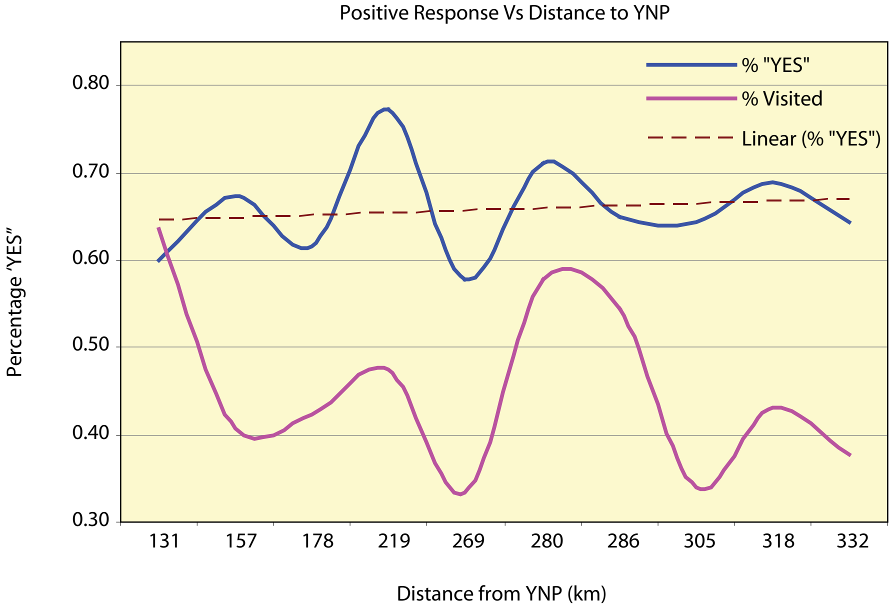
Notes: ++ Parameter estimates are significant at 5 % probability, +++ Parameter estimates are significant at 1 % probability

The decision to contribute to the YEPO was significantly associated with household income. Upper middle income households (those having annual household income between SLR 120,000 and 240,000) showed a significantly higher likelihood of contributing when compared with the reference category. Households with religious attachments and college graduates were also more likely to be willing to contribute towards the YEPO.

A total of 45.4 % of respondents had visited the YPC at least once during their lifetimes. Although previous visitors are expected to be positively associated with willingness to pay for quality enhancement of the resource, our data does not support such association. Previous studies show that appreciation for a national park decreases as the distance to the park increases. Willingness to contribute for enhancement of the YPC (positive contributions = 1; otherwise = 0) was regressed with travel distance as the independent variable. Contrary to the expectation of declining probability to contribute as the distance from an environmental asset increases, the estimated parameter for distance to the YPC in the regression model is positive but statistically non-significant at 10 % probability. The percentage of respondents with positive the WTP and the percentage of respondents who had visited the YPC are arranged by deciles, of distance between the YPC and respective residences in Figure 1.

Our data does not show significant differences in the decision to contribute between urban and rural households. A separate binary logistic regression was done to show the relationship between visitor status and distance to the YPC. We found that the visitor status declined with increasing distance and the estimated coefficient was statistically significant at a 1 % level of probability.

Figure 1. Changes in visitor status and percentage willing to contribute with road distance to YPC.



Based on these findings we can conclude that the decision to contribute does not change with the visitor status, location or the sector of residence of respondents. We conclude that the YPC is valued by the general population of Sri Lanka and this value is generated mainly through non-use values.

Conclusions

Yala National Park in Sri Lanka can be considered a unique environmental resource due to its undisturbed nature, large size, the composition of flora and fauna and the uninhabited stretch of coastline. This research demonstrates that the general population of Sri Lanka values the non-user benefits of the YPC irrespective of household sector, distance to the YPC and their previous experiences with the YPC. Monetary values elicited through CV reveals those improvements to the YPC ecosystem through an assured supply of water generates benefits that are about 20 times that of the net benefits generated by using the same amount of water for rice production.

Acknowledgements

Research for this paper was supported by the PhD Fellowship Program of the International Water Management Institute.

References

Bandara, R.; Tisdell, C. 2005. Changing Abundance of Elephants and Willingness to Pay for their Conservation. *Journal of Environmental Management* 76 (2005): 47-59.

Barbier, E. B. 1989. Economics, Natural Resources, Scarcity and Development. London: Erthscan.

Central Bank of Sri Lanka. 2009. Annual Report -2008. Colombo.

Davis, J. 2005. Private Sector Participation in the Water and Sanitation Sector. *Annual Review of Environment and Resources* 30. 145-83.

Ekanayake, E. R. M.; Abeygunwardena, P. 1993. Valuation of Conservation Commodity of the Sinharaja Forest: Towards Total Economic Value. *Sri Lankan Journal of Agricultural Economics* Vol. 2. Number 1.

Freeman, A. Myrick III. 2003. The Measurement of Environmental and Resource Values: Theory and Methods Resources for the Future Press.

Gleick, P. H.; Wolff, G.; Chalecki, E. L.; Reyes, R. 2002. The New Economy of Water: The Risks and Benefits of Globalization and Privatization of Fresh Water. Oakland: CA. Pacific Institute for Studies in Development, Environment and Security.

International Conference on Water and the Environment (ICWE). 1992. The Dublin Principles. (Available at www.wmo.ch/web/homs/icwedece.html.

Sri Lanka Department of Census and Statistics. 2004. Census of Population and Housing-2001: Final Report. Colombo, Sri Lanka: Department of Census and Statistics.

Sri Lanka Department of Census and Statistics. 2009. Household Income and Expenditure Survey 2006/07: Final Report. Colombo, Sri Lanka: Department of Census and Statistics.

Theesfeld, I. 2004. Constraints on Collective Action on a Transitional Economy: The Case of Bulgaria's Irrigation Sector. *World Development* 32 (2): 251-71.

Whiting, P. J. 2002. Streamflow Necessary for Environmental Maintenance. *Annual Review of Earth and Planet Sciences* 30. 181-206.

World Commission on Water for the 21st Century. 2000. A Water Secure World: Vision for Water, Life, and the Environment: World Water Vision Commission Report. The Hague, the Netherlands.

The Impact of Inappropriate Soil Management on River Water Quality: A Case Study in the Kurundu Oya Sub-catchment of the Upper Mahaweli Catchment, Sri Lanka

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Abstract

The results of many studies have revealed that intensive farming on steep slopes, coupled with over application of fertilizers and accumulation of nutrients in downstream water bodies due to soil erosion, have contributed to environmental hazards in the Upper Mahaweli Catchment Area (UMCA) of Sri Lanka. The encroachment of riparian zones for exotic vegetable cultivation has aggravated this situation. In view of this, a study was conducted in the Kurundu Oya catchment, a micro-catchment of the UMCA, to investigate the soil management practices within the farming systems and their impacts on river water quality. Three villages were selected along the Kurundu Oya: Mahakudugala, Kumbalgamuwa and Batagolla. The study consisted of a survey of 150 households in 2007 and 2008, to gather information on the characteristics of householders and on soil management practices. A soil survey was carried out to analyze the soil fertility of farmlands. Water quality parameters were measured periodically in different sections of a selected stream. The results revealed that nearly 50 % of the riparian zones in the upper catchment of the Kurundu Oya stream are encroached to cultivate potato and other exotic vegetables. In addition, it was observed that over application of fertilizers on the vegetable plots was causing nutrient accumulation and the plots also recorded high levels of phosphorous (P) (above 75 ppm). Results of the water quality analysis showed that nitrate and available P levels were within the standard limits, but nitrate nitrogen (NO_3-N) levels were close to the upper level of the standard limit. Therefore, in order to minimize water pollution, it is strongly recommended that fertilizer application is based on soil tests. In addition, encroachment of sensitive lands has to be addressed. Priority should be given to strengthening institutional capacity in order to facilitate the implementation of existing environmental legislation.

Introduction

The Upper Mahaweli Catchment Area (UMCA) is considered very important to the Sri Lankan economy as it provides the water needed to generate 55 % of the electricity requirement of the country and to cultivate large extents of paddy and other field crops. Year around cultivation of exotic vegetables, including potato, which provides higher returns compared to other crops, is possible because of the suitable climatic conditions prevailing in most parts of the UMCA. Since per capita land availability is continually reducing, farmers have tended to cultivate more intensively to increase their production and income. The tendency to encroach forest reserves has also increased due to high population pressure. It can be observed that continuous cultivation with minimum soil conservation measures and without the required fallow period, has contributed significantly to land degradation in the UMCA. Furthermore, it has reduced the capacity of soil to provide the required amount of plant nutrients for crop growth. Farmers attempt to overcome the problem by adding organic manure and inorganic fertilizers in excess of the recommendations made by the Department of Agriculture (Rajakaruna et al. 2005).

It is a well known fact that leaching of excess water soluble nutrients from agricultural systems adversely affects the quality of drainage water and can impact on downstream water quality. In general, market vegetable gardens in the UMCA are highly vulnerable to soil erosion, and most have reported annual erosion rates of over 75 t/ha thus significantly increasing the sediment yield in runoff and stream water (Stocking 1992). .The transportation of sediments caused by soil erosion from UMCA contributes significantly to the siltation of major reservoirs that are used for hydropower generation and delivering water for irrigated agriculture in the downstream areas. For example, according to a technical report the Rantambe Reservoir silted at a rate of 4.3 % in 1991-1992; Polgolla Reservoir at 2.8 % per annum during 1976-1992; and Victoria Reservoir at 0.08 % rate during 1985-1993.

Kurundu Oya adjoins the Uma Oya catchment and they share a similar land use pattern. Since the 1980s, exotic vegetable cultivation has been expanded to a commercial-scale in the Kurundu Oya catchment and now contributes significantly to household incomes and to the well-being of the community. According to Kumarihamy (2008), the total land extent under market vegetable gardens in the Kurundu Oya catchment is 881 ha. However, the actual land extent is likely to be more than this because some farmers use paddy fields for vegetable cultivation during the yala season or both yala and maha seasons. Since 1984 the area under commercial vegetable farming has increased and the extent of home gardens has declined as home gardens have been converted to intensive vegetable farming systems. Field observations revealed that this is the main cause of high soil erosion in these two catchments. Farmers seem unconcerned about soil conservation, which may be attributed to inadequate agricultural extension services being provided by relevant institutions and the unsatisfactory implementation of legislations against the encroachment of sensitive lands.

Despite this, no systematic study has been conducted with respect to soil erosion and nutrient depletion from the catchment. This study was therefore undertaken to investigate the soil management in the farming systems, particularly market vegetable gardens, in the Kurundu Oya catchment, and its effect on stream water quality. An attempt was also made to identify the institutional gaps which adversely affect the implementation of the Soil Conservation Act at the field level.

Materials and Methods

The studied villages are located in the Kurundu Oya catchment (between $7^0$01' and $7^0$13' N and $80^0$48' and $80^0$55' E), which lies mainly in the mid- and up-country intermediate zones where mean annual rainfall is about 1,700 mm. Three locations were selected along the Kurundu Oya stream representing lower, middle and upper parts of the catchment. These are Batagolla, Kumbalgamuwa and Mahakudugala. Land is the most limiting natural resource in the catchment, because most of the lands are on steep slopes and are not suitable for any use other than natural forests. Batagolla is a village situated at the valley bottom where paddy fields are predominant. Kumbalgamuwa is located in the middle catchment, where rotational farming (paddy in the maha season and vegetable in the yala season) is practiced. Mahakudugala in the upper catchment area consists of tea and intensive vegetable cultivation. Apart from that, home gardening and rain-fed farming are practiced in middle and lower catchment areas for subsistence.

The study consisted of a household survey to gather socioeconomic data, soil analysis to describe soil fertility levels, and water sampling and analysis to asses the existing quality of stream water. A pre-tested questionnaire was used to interview 150 household heads. It included household characteristics, type of farming systems and their management, and questions about the existing institutional set-up in the study area.

Soil samples were collected from each farm allotment belonging to the surveyed household heads. A gauge auger was used to draw soil samples from the surface (0-30 cm depth) and two samples were obtained from each allotment. Soil sampling was carried out prior to land preparation and brought to the Soil Science Laboratory at the Faculty of Agriculture of Rajarata University for analysis. All the samples were air dried and passed through a 2 mm sieve prior to analysis. The particles above 2 mm in diameter were separated and weighed to determine the percentage of the gravel in each sample. Soil pH was measured in a soil: water (1:2.5) suspension, which was stirred occasionally over a 20-minute period, using a pH meter. Electrical conductivity (EC), which is a measure of the concentration of soluble salts, was determined using a digital conductivity meter (Hesse 1971). Organic carbon content was determined by the 'Walkey and Black Method' (Nelson and Sommers 1982). The available phosphorous (P) was measured by 'Olsen's Method'. The exchangeable potassium (K) was estimated by flame photometry. The total nitrogen (N) was determined by distillation of ammonia (NH_3) after Kjeldhal digestion (Bremner and Mulvaney 1982).

Water samples were obtained at 2-week intervals from the selected sampling points on the stream from February to March. A sampling point in the natural forest, served as an uncontaminated control. Other sampling points were established at 100 m intervals along a tributary of the Kurundu Oya in the upper catchment, where intensive vegetable farming is practiced. Water samples were transported to the Soil and Water Engineering Laboratory of the Department of Agricultural Engineering, University of Peradeniya, and stored in a deep freezer until analysis.

For the analysis of suspended sediments, water samples were filtered through 'Whatman 'No.01 filter papers. The sediment retained after filtration was dried at 40^{o}C for 24 hours. It was weighed and compared with the weight of another filter paper after the filtration of an equal volume of distilled water as a control. The dried sediment samples and the supernatants were analyzed separately for different parameters.

The EC, total dissolved solids (TDS) and pH of the water samples were measured using a digital conductivity meter (Thermo Orion Model 145) and pH meter (Lonalyzer Model 407 A), respectively. Nitrate nitrogen and available P were determined colorimetrically using the indophenol blue, the sodium salicylate and the ammonium molybdate/ascorbic acid methods, respectively. The same methodology used to analyze soil samples was followed in sediment analysis.

Results and Discussion

A general description of the selected locations of the study area is given in Table 1.

Table 1. General characteristics of the study locations.

Location	Number of households	Monthly household income (Rs.)	Main farming system	Main soil conservation method	Encroached lands (ha)
Batagolla	121	3,000	Paddy	Bench terraces	5
Kumbalgamuwa	147	7,000	Paddy and vegetable	Bench terraces	23
Mahakudugala	202	12,000	Vegetable	Forward terraces	78

Source: Household survey, 2008

Batagolla is a traditional village in which paddy is the main farming system. Since most of the soils of this area are poorly drained, paddy is the only crop which can be cultivated without much difficulty. The paddy fields are mainly located in valleys (lowland) where water is available in both yala and maha seasons. In general, paddy fields are found in the bench terraces, which are highly stable and less vulnerable to soil erosion. Since paddy tracks are well protected by bunds, the rate of soil loss from the system is minimal (Madduma Bandara 1997). The mean monthly household income in Batagolla is lower than the other two locations, mainly due to low paddy yield. The extent of encroached lands reported in Batagolla is also low, which could be due to low demographic pressure and less demand for paddy farming, especially among the younger generation.

A rotational farming system is practiced in the Kumbalgamuwa micro-catchment. Farmers prefer to cultivate paddy during the maha season because of heavy rainfall. Vegetables are grown in paddy tracks during yala, which provides a better income than the maha season. Since the same tracks are used for paddy and vegetables, the rate of soil erosion reported from the farmlands in the Kumbalgamuwa area is moderate to low.

Mahakudugala is located in the upper catchment (above 1,250 m from mean sea level) and the environment is more favorable for exotic vegetables. Therefore, intensive vegetable farming is predominant and the cropping intensity is above 2.5 (this means the land is cultivated more than two seasons per year). High demographic pressure and increasing demand for exotic vegetables puts pressure on limited land resources in this part of the catchment. As a result, the tendency to encroach forest reserves and riparian zones is remarkably high. The findings of the socioeconomic survey revealed that nearly 78 ha of lands have been encroached in the Mahakudugala micro-catchment, most of which are being used for vegetable cultivation. In general, vegetables are grown in forward sloping terraces, which are not very successful in terms of soil conservation. Stocking (1992) reported that annual soil loss from market vegetable plots in the up-country of Sri Lanka is about 75 t/ha. According to the results of the soil analysis, market vegetable plots recorded the highest gravel content of 33 % in the top soil (0-30 cm depth) compared to other farming systems. These factors very clearly indicate that this farming system is more vulnerable to soil erosion than the others.

Soil Properties of Different Farming Systems

Taxonomically, all the soils in the study area belong to the ultisols (Panabokke 1996). However, the soil pH of different land uses ranged from 5.4 to 6.5 (Table 2). In general, mid- and up-country soils are acidic, mainly due to high leaching. Intensive vegetable farming systems showed slightly higher pH values compared to other land uses. The most plausible reason for this is the incorporation of poultry manure and the application of lime to the fields. These fields were also recorded as having the highest organic material content of 3 % compared to other land uses. In general, animal manure such as poultry and cattle manure are added in high doses to vegetable plots by farmers (Wijewardane and Yapa 1999).

Table 2. Soil properties of different land uses.

Land use	Soil pH (1:2.5) soil:H_2O	Soil EC dS m^{-1}	Gravel (%)	OM** (%)	Available P (ppm)	Exchangeable K (ppm)	Nitrate N(ppm)
Paddy	5.4 ^{b}	0.3 ^{b}	18 ^{c}	1.8 ^{c}	61 ^{b}	124 ^{a}	19 ^{c}
Paddy - veg	5.9 ^{b}	0.4 ^{b}	25 ^{b}	2.4 ^{b}	67 ^{b}	137 ^{a}	37 ^{b}
Forest	5.7 ^{b}	0.1 ^{c}	26 ^{b}	2.8 ^{b}	18 ^{c}	48 ^{b}	19 ^{c}
Vegetable	6.5 ^{a}	0.6 ^{a}	33 ^{a}	3.3 ^{a}	103 ^{a}	142 ^{a}	56 ^{a}

Source: Soil survey, 2008

Note: *Means in a single column for a given property with same superscript are not significantly different at $p = 0.05$. ** Organic Matter

The EC of vegetable growing soils showed the highest value, compared to the other samples, of 0.6 dS m^{-1}, indicating a medium salinity level. One reason for this may be the over application of chemical fertilizers to meet the relatively high demand for plant nutrients by exotic vegetables. At the same time, the available P level of the vegetable soils was 103 ppm, which is five times higher than the P content of the forest soils. According to the FAO standards, 30 ppm of P in agricultural soils is considered to be very high, but all the farming systems studied exceeded this amount. Similarly, reported K and NO_3–N levels in vegetable-growing soils were significantly higher than the crop requirements. This could be because, as reported by Rezania et al. (1989) and Gunawardane et al. (1998), up-country farmers apply very high doses of chemical fertilizers to their vegetable plots.

The gravel content (particles > 2 mm in diameter) of the top soil (0-30 cm depth) is one of the soil erosion indicators widely used by researchers (Botschek et al. 1998). The vegetable-growing soils reported the highest gravel content of 33 %, which is significantly higher than all other land uses. Paddy fields, which are well protected, showed the lowest gravel content of 18 % in the top soil. Therefore, it is clear that, intensive vegetable farming systems are more vulnerable to soil erosion than other farming systems practiced in the catchment.

Quality Parameters of the Stream Water

Shallow groundwater contributes to maintaining the base flow of natural streams, especially during dry spells. Jayakody (2002) and Rajakaruna et al. (2005) found that there is a positive relationship between the ion concentration of the soil and the groundwater in up-country dug wells.

The water sample taken from the stream at the natural forest showed the highest pH value of 6.8 and was closest to neutral (Table 3). A reduction in pH was observed along the stream and the lowest value of 5.9 was reported at the 300 m sampling point. Jayakody (2002) stated that well water in the Pattipola area is acidic because basic cations that are dissolved in the water are absorbed by the algae and other aquatic plants. The acceptable range of pH for irrigation water is 6.5 to 8.5 (Ayers and Westcot 1985). According to the recommendation of the National Water Supply and Drainage Board of Sri Lanka, the acceptable pH range for drinking water is 6.5 to 9.0. According to these standards, the acidity of the stream water is slightly higher than the acceptable range for drinking and irrigation.

Table 3. Water quality along a natural stream in the Kurundu Oya catchment.

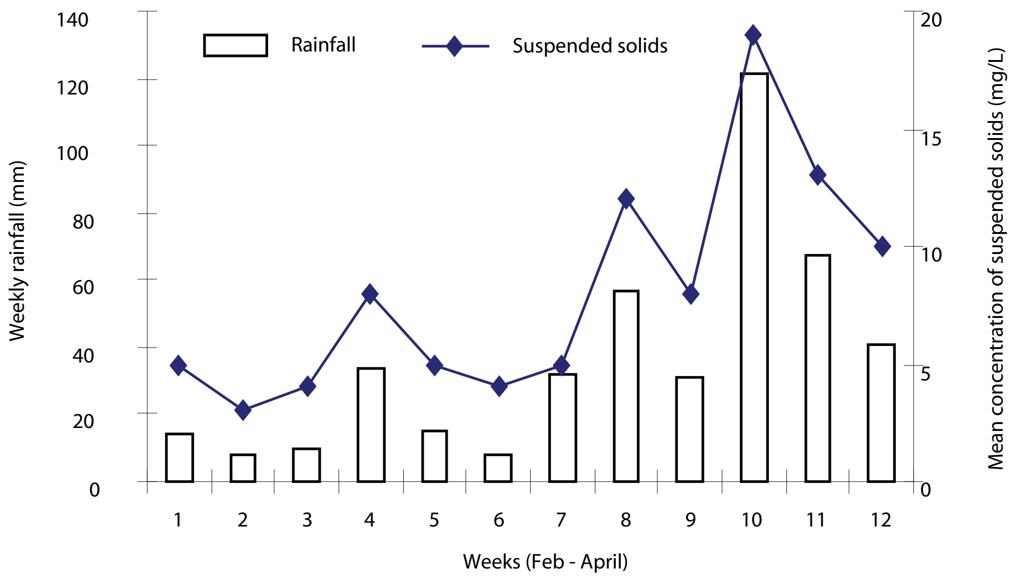
Sampling point	pH	EC dS m^{-1}	TDS (mg^{-1}/L)	Available P (mg^{-1}/L)		Nitrate N (mg^{-1}/L)	
				particulate	dissolved	particulate	dissolved
Forest	6.8	0.01	7	0.2	0.00	0.4	0.00
100 m	6.4	0.02	10	0.79	0.17	2.6	0.52
200 m	6.0	0.11	55	1.8	0.25	5.2	1.2
300 m	5.9	0.13	68	2.9	0.28	9.7	2.4
400 m	6.0	0.13	62	2.6	0.27	9.2	2.3

The EC of the water samples ranged from 0.01 to 0.13 dS m-1. The water samples from the stream at the natural forest showed the lowest EC and TDS values. However, both parameters increase as the stream passes through the vegetable farming area. Gunawardane et al. (1998) and Wijewardane and Yapa (1999) emphasized that the over application of chemical fertilizer may increase the soluble salt content of shallow groundwater in up-country vegetable-growing areas. The influence of vegetable farming on the nutrient level of the stream water is also clearly reflected by the comparison of results given in Table 3. The available P and N levels of the stream water in the natural forest are remarkably low compared to other sampling points. Collins and Jenkins (1996) reported that in the middle hills of the Himalayas in Nepal, agricultural catchments contributed more to the nutrient content of stream water than the forested catchments. They further stated that mineral fertilizers and organic manure applied to the agricultural lands significantly affected the water quality of the streams.

A simple comparison between two fractions of nutrients (particulate and dissolved) in stream water is also given in Table 3. It reveals that more nutrients are transported with the solid fraction than the dissolved fraction. Therefore, higher concentrations of nutrients in streams tend to be associated with higher levels of suspended sediments. Kothyari (2004) observed a strong relationship between rainfall-runoff and nutrient losses in the agricultural lands of Bhetagad watershed in the Central Himalayas in India. Collins and Jenkins (1995) stated that the major dynamics of water chemistry of streams in the Middle Himalayas in Nepal occur during the monsoon due to surface runoff and the return flow from agricultural lands.

The fluctuation of SS in stream water and the weekly rainfall over 12 weeks from February to April is plotted in Figure 1. It is clear that high sediment concentrations coincide with high rainfall events. Most of the vegetable plots in upper Kurundu Oya catchment are located in forward sloping terraces from which soil is easily removed during monsoon periods. In addition, available plant nutrient levels in the soil are extremely high for vegetable cultivation compared to other land uses (Table 2). Therefore, vegetable farming systems can be considered to be the main non-point pollution source with respect to the stream water pollution in the area.

Figure 1. The relationship between rainfall and the average concentration of SS of stream water.



Nutrient Management in Vegetable Farming Systems

It is a common myth among farmers that the higher the rate of fertilizer application, the higher is the crop yield. Therefore, they tend to apply high doses of mineral fertilizers and organic manure in order to artificially build-up soil fertility. However, such an application may actually induce nutrient imbalances in the soil and adversely affect the crop yield. Furthermore, the existing fertilizer recommendations for vegetables in Sri Lanka often consist of one predetermined rate of N, P and K for vast areas of vegetable production. Such recommendations assume that the nutrient requirements of vegetables are constant irrespective of the temporal and spatial variability of plant nutrients in the soil. In reality, supplemental nutrient needs of a crop can vary greatly between fields, seasons and years due to the differences in crop and soil management, and climate (Porch and Hunter 1999). Hence, the management of nutrients for vegetables requires a new approach that involves an adjustment to the application of N, P, and K to accommodate field-specific needs.

Site-specific Nutrient Recommendations

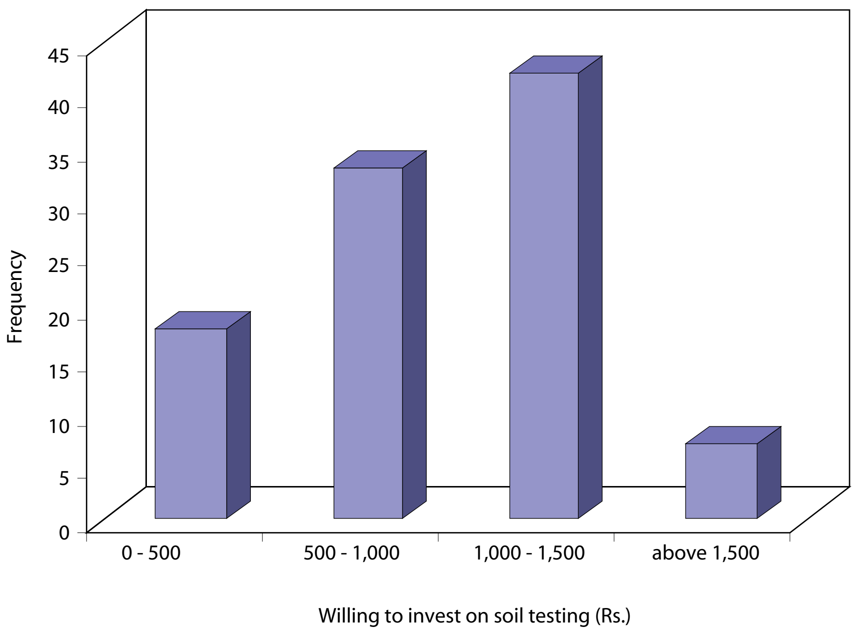
Many European countries use soil fertility maps to make fertilizer recommendations for a vast range of crops, often using sophisticated technologies such as EC mapping to define soil types. These maps are highly accurate and very useful for prescribing site-specific fertilizer recommendations. However, this type of technology is more applicable to farms with thousands of hectares than to the highly fragmented and scattered plots seen in the Kurundu Oya catchment, where the average farm size for vegetable cultivation is about 0.25 ha (Household survey 2008). Since farmers practice different management systems, the spatial and temporal variability of the soil fertility is extremely high. Therefore, soil test-based fertilizer recommendations could be more effective for this kind of situation than any other method.

In this site-specific nutrient management, crops are fed according to the nutrient availability at the site so that the quantity of fertilizer used will fill the deficit between the nutrient needs of the crop and the nutrient supply from naturally-occurring indigenous sources such as soil and organic amendments (Portch and Hunter 1999). Site and crop-specific fertilizer application rates can reduce the accumulation of excess amounts of plant nutrients in the soil, which are very likely to be removed with surface runoff and may enter waterways.

The sample population was asked about their preference for investment in soil-test-based fertilizer recommendations. It was found that nearly 50 % was willing to invest more than Rs.1,000 for soil testing per annum (Figure 2), and that almost all the farmers prefer to practice soil test-based fertilizer recommendations than to add fertilizer according to the existing broad recommendations.

One practical difficulty with soil test-based fertilizer recommendation however, is the cost of soil analysis. The capacity of government research institutes will not be adequate to cater for the whole farming community. Therefore, the private sector should be involved in the process and assistance should be provided to enable them to develop their facilities.

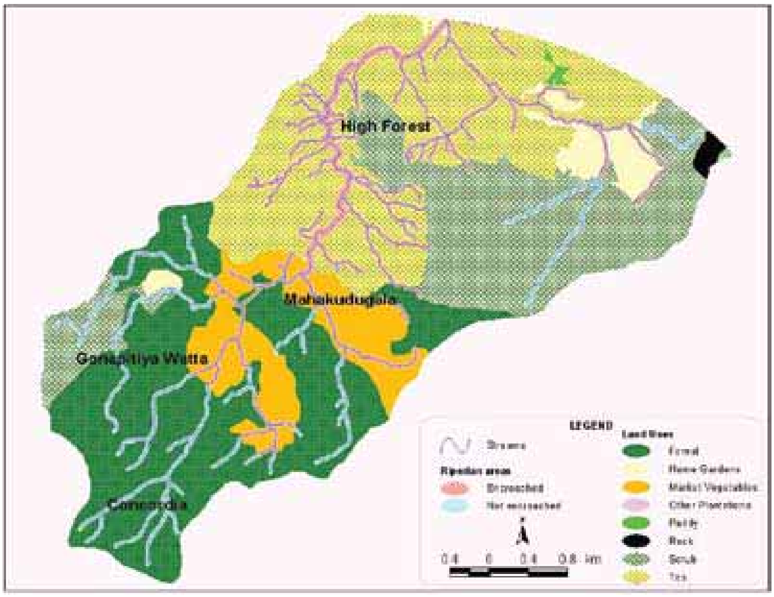
Figure 2.   Farmers' willingness to invest on soil testing per annum (n =100).



Institutional and Legal Framework

Over fertilization, inefficient soil conservation and encroachment of sensitive lands such as forest reserves and riparian zones are closely associated with intensive vegetable farming in the Kurundu Oya catchment. Most of the riparian zones in the tea estates have also been encroached by state workers for vegetable farming (Figure 3).

Figure 3. The extent of encroached riparian zones in a part of the Kurundu Oya catchment.



Source: Land use mapping of Kurundu Oya catchment, 2008

There is existing legislation to control some of these illegal practices and reduce environmental damage, including 13 major pieces of legislation to ensure protection and sustainable utilization of land resources, but unfortunately there is no statute that applies to the management of lands in the Kurundu Oya catchment (Amarasekara et al. 2008). Some of the legislation that is in existence includes the Forest Ordinance (1907), the Soil Conservation Act (1951) and the National Environmental Act (1980), which are all closely linked with the mitigation of soil erosion and prevention of land encroachments. However, these documents provide only a legal platform and the institutional set up does not have sufficient capacity to implement such legislation at the field level. In addition, several government authorities have mandates to operate in the area but there is a lack of co-ordination between them and inadequate numbers of grass-root level officers to implement the Acts. These are major factors that hinder proper land management in the study area.

The Soil Conservation Act, which was implemented by the Natural Resources Management Centre (NRMC) of the Department of Agriculture, is the most powerful piece of legislation with respect to soil erosion and soil conservation. It was amended in 1996 to make provision for the establishment of the Soil Conservation Board, with representation from relevant government agencies, and for the establishment of a Soil Conservation Fund. Powers under the Act have also been delegated to Divisional Secretaries but the Soil Conservation Board has not yet been established. At the same time, the lack of field-level officers to implement the Act is a major limitation. The Agricultural Instructors, attached to the Provincial Departments of Agriculture and under the purview of the Provincial Councils, are expected to implement the Act at the field level; but the NRMC is under the Central Government of Sri Lanka. Since these two institutions function in two different administrative frameworks, many controversies have occurred in the implementation of the Act.

In the Kurundu Oya catchment there are only three Agricultural Instructors to cover the whole catchment, which is cultivated by about 4,500 families. The Agricultural Research and Development Assistant (ARDA) is the only field-level officer who can assist Agricultural Instructors to implement the Act. However, ARDAs are attached to the Agrarian Services Department of the Central Government, which has no direct link with the Provincial Councils. Therefore, priority should be given to introduce a grass-roots level category of extension workers under the Department of Agriculture, not only for the implementation of the Soil Conservation Act, but also to assist farming communities to solve their field problems. In addition, the Soil Conservation Board should be established without delay to empower the Divisional Secretaries so that they can in turn implement the Act at the field level.

Conclusions

Intensive vegetable farming is currently a major land use in the upper part of the Kurundu Oya catchment. Due to the high market demand and favorable climate, farmers prefer to grow exotic vegetables than other field crops. However, the increasing population is putting more pressure on limited land resources, which in turn creates a tendency to encroach forest and stream reservations, as these are the only land parcels available in the catchment. Such inappropriate land management practices associated with intensive vegetable farming have caused many problems such as soil erosion and sedimentation of water bodies. It was found that sediment carries more nutrients than the dissolved fraction, and hence, heavy sediment loads coming from vegetable plots with surface runoff may increase the nutrient levels in the stream water. Over application of fertilizers and inefficient soil conservation techniques associated with vegetable farming systems have also aggravated the situation. Therefore, it is proposed that fertilizer recommendations should be made according to soil tests rather than being based on a single predetermined rate, as this would reduce the accumulation of nutrients in both soil and water bodies. In addition, priority should be given to implementation of the Soil Conservation Act at the field level by strengthening the existing institutional set up.

Acknowledgements

The financial support given by the Crossing Boundaries Project of the PGIA, University of Peradeniya, Sri Lanka is greatly appreciated.

References

Amarasekara, M. G. T. S.; Indrarathna, S. P.; Kumaragamaga, D.; Sultanbava, F. 2007. Formulation and Testing Site-specific Fertilizer Recommendation for Bitter Gourd (*Momordica charantia*. L). *Tropical Agricultural Research* 19: 210-218.

Amarasekara, M. G. T. S.; Dayawansa, N. D. K.; De Silva, W. P. R. P. 2008. 'Institutional Aspects of Implementation of Land and Water Policies in the Upper Mahaweli Catchment, Sri Lanka'. Proceedings of the International Conference on Water Resources Policy in South Asia. Colombo, Sri Lanka.

Ayers, R. S.; Westcot, D. W. 1985. Water Quality of Agriculture, Irrigation and Drainage. Paper No. 29, FAO, Rome. p. 174.

Botschek, J.; Skowronek, A.; Jayakody, A. N. 1998. Soil Degradation, Soil Assessment and Soil Rehabilitation in a Former Tea Growing Area of Sri Lanka. *Applied Geography and Development* 51: 94-105.

Bremner, J. M.; Mulvaney, C. S. 1982. Nitrogen-total. In Methods of Soil Analysis, Agronomy Monograph, 9. (2nd Ed) Madison, USA. pp. 595-615.

Collins, R.; Jenkins, A. 1996. The Impact of Agricultural Land Use on Stream Chemistry in the Middle Hills of the Himalayas, Nepal. *Journal of Hydrology* 185 137-150.

Forest Ordinance in Sri Lanka. 1907. Ministry of Environment and Natural Resources, Sri Lanka.

Gunawardane, E. R. N.; Rajapakse, U.; Nandasena, K. A.; Rosier, P. T. W. 1998. 'Water Quality Issues in the Up-country of Sri Lanka'. Proceedings of the final workshop of the University of Peradeniya – Oxford Forestry Institute Link Project, ed. H.P.M. Gunasena. University of Pertadeniya, Peradeniya, Sri Lanka. pp. 37-74.

Hesse, P. R. 1971. 'A Text Book for Soil Analysis'. London, U.K.: Wilson Cloverand Sons Limited. pp. 30-33.

HR Wallingford. 1995. Sedimentation Studies in the Upper Mahaweli Catchment in Sri Lanka. Report EX 3201. Oxon: HR Wallingford Limited.

Jayakody, A. N. 2002. 'Soil Fertility and Nutrient Contamination of Water in a Hill Catena of Sri Lanka under Intensive Cropping'. Proceedings of the 17th World Congress of Soil Science, Symposium on Soil Fertility as an Ecosystem Concept, Thailand.

Kothyari, B. P.; Verma, P. K.; Joshi, B. K.; Kothyari, U. C. 2004. Rainfall-Runoff-Soil Nutrient Loss Relationship for Plot Size Areas of Bhetagad Watershed in Central Himalaya, India. *Journal of Hydrology* 293: 137-150.

Kumarihamy, R. M. K. 2008. Sustainable Land Use Planning for Kurundu Oya Catchment: A Participatory GIS Approach for Integrated Water Resources Management. M.Sc dissertation, Postgraduate Institute of Agriculture, University of Peradeniya, Sri Lanka.

Madduma Bandara, C. M. 1997. 'Adverse Impact of Land Use and Improper Land Management Practices on Slope Stability and Landslides'. Proceedings of National Symposium of Landslides, NBRO, Sri Lanka.

National Environmental Act. 1980. Ministry of Environment and Natural Resources, Sri Lanka.

Nelson, D. W.; Sommers, L. E. 1982. Organic Carbon. In Methods of Soil Analysis. Agronomy Monograph, 9. (2nd ED) Madison USA.

Panabokke, C. R. 1996. Soil and Agro-ecological Environment of Sri Lanka. Natural Resources Series. Colombo, Sri Lanka: Energy and Science Authority. p. 220.

Porch, S.; Hunter, A. 1999. 'A Systematic Approach to Soil Fertility Management and Improvement'. Hong Kong, Canpotex Limited.

Rezania, M.; Yogarathnam, V.; Wijewardane, J. D. H. 1989. Fertilizers Use on Potato in Relation to Soil Productivity in Up-country Areas in Sri Lanka. Field document No. 3:35. Rome, Italy: FAO.

Rajakaruna, R. M. P.; Nandasena, K. A.; Jayakody, A. N. 2005. Plant Nutrient Contamination of Shallow-Groundwater in Intensive Vegetable Gardens of Nuwara Eliya. *Tropical Agricultural Research* 17:80-92.

Soil Conservation Act. 1951. Ministry of Agriculture Development, Sri Lanka.

Stocking, M. A. 1992. Soil Erosion in UMC Forest Land Use Mapping Project. Technical Report No.14. Environment and Forest Conservation Division, Mahaweli Authority of Sri Lanka, Polgolla.

Wijewardane, J. D. H.; Yapa, U. W. S. P. 1999. Effect of the Combined Use of Animal Manure and Chemical Fertilizer on Potato and Vegetable Cultivation in the Up-country of Sri Lanka. *Sri Lankan J. Agric. Sci.* 36: 70-82.

Availability and Spatial Variability of Plant Nutrients in Paddy Fields of Wilgoda Irrigation Scheme in Kurunegala

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Abstract

A study was carried out in the maha season of 2008/2009 to gather information on the status of plant nutrients and their spatial variability in paddy fields in the Wilgoda irrigation scheme, where wastewater is used for irrigation purposes throughout the year. Soil samples were collected from 56 sampling points at upper (Peellawala), middle (Illuppitiya) and lower (Galayaya) parts of the area. Geographic positions of the sampling points were recorded using a Geographical Position System (GPS). Soil samples were analyzed for pH, available phosphorus (P), exchangeable concentrations of potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and zinc (Zn). In comparison to nutrient contents recorded for paddy growing soils in other parts of Kurunegala by Mapa et al. (2005), this study showed higher levels of P, K, Mg and Na in all study sites. Significant variability in nutrient availability was observed both between sites as well as within a site. Although the inherent K content of paddy soils in Kurunegala is 29-39 mg kg-1, the recorded average K contents at Galayaya and Peellalwala were 59.7 and 67.0 mg kg-1, respectively. Around 20 % of the area had K contents above 78 mg kg-1, which is the critical K level for rice. The reported P content of paddy growing soils in Kurunegala is 7 mg kg-1 but 92 % of the area in Peelalwala had P contents above 12 mg kg-1. The majority of the paddy fields in Peelalwala and Galeyaya had Mg contents above 400 mg kg-1 compared to 89-396 mg kg-1 reported by Mapa et al. (2005). The sodium contents observed in Peellawala and Galayaya were 156 and 167 mg kg-1 respectively, which is significantly higher than the Na contents of 46-69 mg kg-1 reported for other Kurunegala paddy growing soils. These results reveal an increase in all nutrients in the upper part of the irrigation area (Peellawala) where wastewater first enters the paddy fields. Concentrations of highly soluble K, Na and Mg congregate in the lower site while less soluble P and Zn are deposited in the middle site. It can be suggested from these results that regular monitoring of plant nutrient availability in the Wilgoda scheme will help in understanding nutrient supply in wastewater and its movement across irrigated fields. The differences in plant nutrients within a site were particularly evident in the map of spatial variability, suggesting that site-specific fertilizer recommendations should be made to achieve the maximum yield with limited fertilizer costs.

Introduction

More than 90 % of rice cultivars grown in Sri Lanka are new improved varieties (NIV) and their yield potential is over 10 t ha-1 under favorable growing conditions (Jayawardene 2003). The present national average yield of 4.07 t ha-1 is far below these values (Central Bank 2006). Scientists suggest many reasons for this gap between potential yield and realized yield at the farm level, but from the soil science point of view, depletion and imbalance of plant nutrients are the major factors creating this difference (Panabokke 1978).

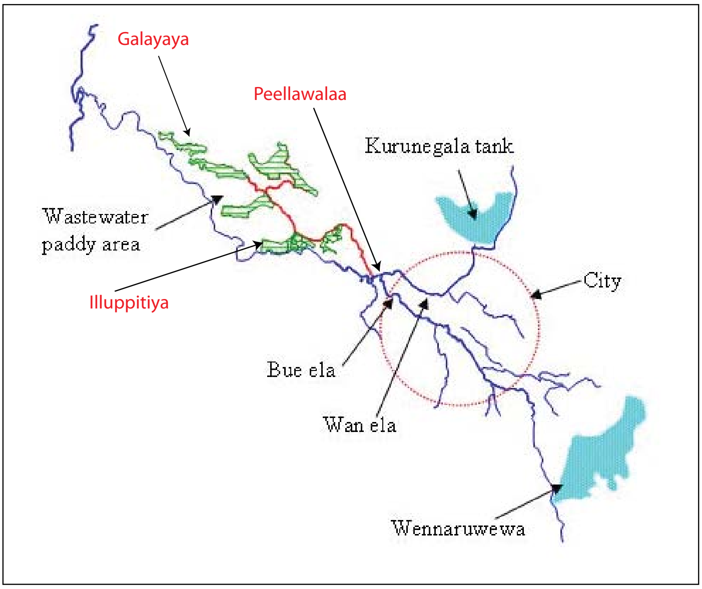
Kurunegala District is a major rice growing area in Sri Lanka where water is the limiting factor for potential rice yields (Central Bank 2006). Therefore, water from different sources is used for supplementary irrigation. Since high-quality water is not available in the required quantities, low-quality wastewater is also used to irrigate paddy fields on certain occasions. The identification of nutrient levels or hazardous compounds in these fields provides useful information to facilitate proper planning for the management of wastewater in agriculture. Amarasiri (2008) suggested that water quality parameters that have a direct effect on irrigated agriculture are organic content; concentration of salts; availability of nutrients and pathogen levels. Wastewater contains a considerable concentration of nutrients, including nitrogen (N), phosphorus (P) and potassium (K) (Amarasiri, 1973). The levels of accumulation of nutrients in paddy fields vary from place to place because of the level of water received and the movement of soluble plant nutrients. An imbalance in fertility levels may appear in paddy fields and measures have to be taken to improve the productivity of these lands by managing all these nutrients effectively. To achieve this goal, spatial nutrient availability within paddy fields should be understood properly.

This paper reports on the availability of plant nutrients and their spatial variability in paddy fields in the Wilgoda irrigation scheme, where wastewater is used for supplementary irrigation in both *yala* and *maha*.

Materials and Methods

Wennaru Wewa, which is situated at the southern end of the Kurunegala District Secretariat Division, has a capacity of 1.8 million m^3 (1,490 acre feet) and serves a command area of 186 ha in both the yala and maha seasons. There are two main canals that provide water for downstream irrigation. The left bank main canal irrigates 93 ha and feeds the Wilgoda Anicut (weir) via the Bue Ela. The Bue Ela and another stream, the Wan Ela, also drain the urban area of Kurunegala City as they flow via residential, commercial and cultivated areas, collecting untreated sewage and wastewater that is discharged into the canals. The Bue Ela and Wan Ela join at Wilgoda anicut, which is operated to provide irrigation water to the paddy fields. The Wilgoda scheme has 137 farmer families cultivating 53.4 ha of irrigable lands. They cultivate paddy twice a year and hardly grow any other crops. There are five paddy areas spatially distributed over the command area of Wilgoda. They are Peellawala, Illuppitiya, Kahatagaha, Nelugahapitiya and Galeyaya. Of these, Peellawala, Illuppitiya and Galayaya were selected for the study (Figure 1).

Figure 1. Schematic diagram of the study site.



The distribution pattern of the sampling points was chosen to be similar to the distribution pattern of the drainage classes of the rice tracts. Accordingly 17, 18 and 15 soil samples were collected from Peellawala, Illuppitiya and Galayaya, respectively (Figure 2). Geographical positions of sampling locations were recorded using a Geographical Position System (GPS).

In each location, soils were augured up to 15 cm and composite soil samples of 500 g were collected from each sampling point. They were packed in polythene bags and transported to the laboratory, where they were air-dried, crushed and passed through a 2 mm sieve. Processed soil samples were analyzed for pH, available P, exchangeable K, Ca, Mg, Na, and Zn. All analyses were replicated twice. Sampling points were taken as parameters and attributes tables were created. Analytical data were tabulated and thematic maps were prepared using Arc View 3.3 software.

Figure 2. Sampling points in experimental sites.

Results

The soil parameters were mapped to understand spatial variation and the averages were also compared to data in the literature for other paddy areas in Kurunegala (Table 1).

Table 1. Some chemical properties of the soils in the feeding area of the Wilgoda scheme and for paddy growing soils in the Kurunegala District (IL1).

Soil property	Location			
	Peellawala	Illuppitiya	Galayaya	Kurunegala Districtct
PH value (1:2.5 water)	5.6 (0.02)	5.1 (0.25)	5.6 (0.06)	5.3 – 6.6
Olsen P (mg/kg)	11.50 (3.29)	10.51 (4.81)	8.53 (2.18)	6
Exchangeable K^a (mg/kg)	59.76 (21.37)	44.59 (9.85)	67.03 (23.76)	20- 39
Exchangeable Zn^b(mg/kg)	1.92 (1.03)	1.25 (0.87)	0.74 (0.33)	NA
Exchangeable Fe^a (mg/kg)	29.6 (0.71)	26.1 (2.65)	27.0 (1.00)	NA
Exchangeable Na^a (mg/kg)	156.14 (42.12)	67.38 (35.42)	169.68 (118.80)	46- 69
Exchangeable Cu^a (mg/kg)	Very low	Very low	Very low	NA
Exchangeable Ca^a (mg/kg)	456.44 (85.15)	467.71 (273.12)	403.33 (77.21)	600 - 1,460
Exchangeable Mg^a (mg/kg)	505.39 (63.84)	250.21 (26.16)	420.18 (79.85)	84 – 396

Source: Mapa et al. 2005
Note: Figures in brackets show the variation; [a]1N NH_4OAC (pH=7) Extraction [b]1N HCL Extraction

The soil pH in the area ranges from 5.1 to 5.6 in the top soil (Table 1) and varies from site to site. Peellawala, which is situated in the upper part of the canal, had the highest average pH of 5.6 and Illuppitiya, which is situated in the middle part of the canal, had the lowest average pH of 5.1 (Figure 3). The variation of soil pH within a site was higher in the Galayaya site. Thirty-eight percent of the area under Galayaya had a pH below 5.5 while 16 % of the area had pH above 6. The difference in pH in the lower and middle parts of the canal may be due to the movement of basic ions from the upper part of the canal to the lower part of the canal.

Calcium levels are on average below those recorded by Mapa et al. (2005) for rice growing soils in the low-country intermediate zone (IL1) but vary between and within the sampling sites, especially in Illuppitiya where there are areas with Ca concentrations as high as 1,000 mg kg-1 (Table 1 and Figure 4). The critical Ca concentration for rice is 600 mg kg-1 (Bandara 2005). As such, the Ca concentrations in many areas in the Wilgoda irrigation scheme are not ideal for rice production.

The magnesium content of the soils in the upper and lower parts of the area are higher than recorded by Mapa et al. (2005) and are greater than those in the middle part (Table 1 and Figure 5). It is assumed that Mg enters in the wastewater, reaches the upper part of the canal and ultimately accumulates in the lower part of the canal.

Similar to Mg concentration, the average Na concentration was higher in the upper and lower parts (Figure 6). Average Na concentrations in Peellawala, Illuppitiya and Galayaya are 156, 67 and 169 mg kg-1, respectively (Table 1). About 20 % of the area in Peellawala had Na contents above 200 mg kg-1.

Figure 3. Variation of pH in three experimental sites.

Figure 4. Variation of Ca concentration in three experimental sites.

Figure 5. Variation of Mg concentration in three experimental sites.

Figure 6. Variation of Na concentration in three experimental sites.

Illuppitiya, which is situated in between Peellawala and Galayaya, had a sodium content, below 100 mg kg-1 in the whole area, whereas 10 % of the land in Galayaya had sodium contents above 200 mg kg-1. Irrigation water containing soluble Na and poor drainage may be the reasons for increased Na levels in the top and bottom parts of the feeding area.

The average available P in the topsoil was 11.5, 10.5 and 8.53 in mg kg-1 in Peellawala, Illuppitiya and Galayaya, respectively, which is above the levels for other paddy areas in Kurunegala, (Table 1). Eighty-two percent of the area in Galayaya had a P concentration of 5-10 mg kg-1, while 92 % of the area under the Peellawala site had P values between 10-24 mg kg-1 (Figure 7). These figures suggest that the wastewater is supplying extra P or excess fertilizer is being added (Amarasiri 2008). This theory is further justified by the way the soil P content declines towards the end of the irrigation scheme. The critical P level reported for rice by Doberman and Fairhurt (2000) is 10 mg kg-1. Accordingly, Peellawala has enough P for rice but Galayaya does not.

The K levels in all three sample areas are greater than those for other paddy growing soils in the District (Table 1 and Figure 8). Average K concentration in Peellawela is 59 while that of Illupitiya and Galayaya is 44 and 67 mg kg -1 respectively (Table 1). About 20 % of the area in Peellawala and Galayaya has K levels above 78 mg kg -1. Total area in Illuppitiya has K levels below 78 mg kg -1 (Figure 8). As with P, the origin of the K may be the wastewater used to irrigate the fields or fertilizers applied to crops in excess of requirements (Amarasiri 1973). K is a highly soluble nutrient and that may be the reason for the higher level of K found in the upper part and lower parts of the scheme.

A significant variation in exchangeable Zn was found in the three experimental sites. Zn levels in Peellawala and Illuppitiya are higher than 1 mg kg-1, which is the critical Zn level for rice cultivation (Doberman and Fairhurt 2000). Except in a few isolated pockets, a low level of exchangeable Zn (<1 mg kg-1) was observed in Galayaya (Figure 9 and Table 1).

Figure 7. Variation of P concentration in three experimental sites.

Figure 8. Variation of K concentration in three experimental sites.

Figure 9. Variation of Zn concentration in three experimental sites.

Conclusions

The differences observed within a paddy growing area (known as a yaya) suggest that it is important to identify spatial changes in nutrient concentrations in wastewater and their attenuation as the water is distributed over the fields. This could be converted into thematic maps of nutrient parameters. This can be used to develop a simple but meaningful guidance on fertilizer application to supplement the generic guidance given for an area. The plot-to-plot differences were particularly evident, as shown in the maps, which may be due to the high nutrient concentration of the wastewater. Considering all these factors, attention should be given to exploring the full potential of the paddy lands in the Wilgoda irrigation scheme by preventing the accumulation of unnecessary levels Na and Mg, and recommending site-specific fertilizer management to make use the P, K and Zn nutrients brought with the wastewater.

Acknowledgements

Authors wish to acknowledge the financial assistance given by Wastewater Agriculture, Sanitation and Poverty Alleviation in Asia (WASPA Asia) Project to carry out this study.

References

Amarasiri, S. L. 1973. Water Quality of Major Irrigation Tanks in Sri Lanka. *Trop. Agric*. 129: 18-22.

Amarasiri, S. 2008. 'Caring for Water'. Sri Lanka Nature Forum (SLNF), 546/3, Wata Mawatha, Gangodawila, Nugegoda, Sri Lanka.

Bandara, W. M. J. 2005. Nutrient Requirement and Identification of Nutrient Deficiencies in Rice. Bulletin No. 4, Soil Science Society of Sri Lanka.

Central Bank of Sri Lanka. 2006. Annual Reports. Department of Censes and Statistics, Colombo, Sri Lanka: Central Bank of Sri Lanka.

Doberman, A.; Fairhurt, T. H. 2000. 'Rice Nutrient Disorders and Nutrient Management'. Oxford Graphic Printers Pte. Ltd.

Jayawardene, S. S. B. D. G. 2000. 'Past Present and Future of the Golden Grain, Rice in Sri Lanka'. Proceedings of the Rice Congress.

Jayawardene, S. S. B. D. G. 2003. Past Present and Future of the Golden Grain, Rice in Sri Lanka. In: *Rice Congress* 2000, eds. D. S. De. Z.Abeysiriwardane, D. M. N. Dissanayake and L. Nugaliyadda. Department of Agriculture, Peradeniya, Sri Lanka: Department of Agriculture. pp 15-23.

Mapa, R. B.; Dassanayake, A. R.; Nayakekorale, H. B. (Eds.) 2005. 'Soils of the Intermediate Zone of Sri Lanka'. Special publication, No. 4. Survodaya Vishva Lekha, 41, Lumbini Avenue, Ratmalana, Sri Lanka.

Panabokke, C. R. 1978. 'Rice Soils of Sri Lanka'. In *Rice and Soils*. International Rice Research Institute, Los Banos, the Philippines: International Rice Research Institute.

Assessment of Risks to Water Bodies due to Residues of Agricultural Fungicide in Intensive Farming Areas in the Up-country of Sri Lanka using an Indicator Model

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Introduction

Indiscriminate use of agrochemicals poses a major environmental threat to surface and groundwater. Intensive vegetable cultivation on the steep slopes of up-country hills requires extremely high levels of pesticides (insecticides and fungicides) and fertilizers to maintain high yields and profitability. Farmers do not necessarily follow the doses and frequencies recommended in the instructions but apply higher doses more frequently, as they believe that this will increase yields. The implications of these decisions are not considered by farmers due to the lack of information and understanding of the environmental pathways of chemicals after application. In addition, the methods available to account for the variability of soils, climate and other factors influencing the risk of pesticide use are complex.

Potato cultivation in Nuwara Eliya, Bandarawela and Welimada Sri Lanka is a good example of the effects of excessive pesticide use. In these areas precipitation exceeds 1,830mm per annum and crops are affected by a number of diseases and insect attacks, such as late blight caused by Phytopthora infestance. The prevailing misty conditions also promote fungal growth requiring famers to use contact and systemic fungicides for prevention. Lack of understanding of pesticide pathways and the desire to ensure that the disease is under control often lead to overdoses and higher frequency application of pesticides.

An agrochemical applied to a crop may undergo a number of complex processes before the original chemical and its by-products lose their activity or the potential to harm the environment or life forms. The key pathways involved in the fate of agrochemicals are: photo decomposition by sunlight; adsorption by soil organic and clay matter; degradation or decomposition by microbial action; transport through the soil matrix by percolating water (from rain or irrigation); overland runoff or mass transport dissolved in water or attached to sediments (soil erosion); volatilization into the atmosphere and wind transport along with dust (wind erosion). These processes occur simultaneously or certain processes predominate over others depending on agro-climatic conditions, which include: strength of UV radiation in sunlight; extent of rainfall or irrigation; slope steepness; wind and water erosion potential; soil porosity; soil organic carbon; soil pH; extent of macropores in soil due to cracks, roots and structure; soil microbial activity; temperature; and humidity. It is possible to measure some of the individual processes but to understand the net effect of an applied agrochemical in the environment is a difficult task.

As a result of such complexities, determining the potential of pesticide residues to contaminate surface and groundwater is a challenge. Therefore, the users of pesticides, mainly farmers, do not have an efficient way of accessing the information related to pesticide risks or the support necessary for the judicious use of pesticides. Monitoring pesticide residues in ground and surface water is considered a possible mechanism to help in the control of pollution but the analytical techniques available today for pesticide residue analysis in water and soil are costly and sometimes lack the sensitivity to analyze pesticides at the concentration levels present in typical soil-water systems, even immediately after their application.

At the same time, the number of kidney failures and diseases, the causes of which is as yet unclear, are on the rise. Although these illnesses are not directly linked or proven to be related to pesticides, it is known that contamination of water by pesticide residues at very low levels can induce health-related problems. The cost of treatment of kidney failure is high, it puts an enormous strain in national budgets and above all it impacts on the quality of life of the affected people and their relatives.

Therefore, it is necessary to better understand the ultimate fate of pesticides in different agro-climatic environments and adopt certain best management practices to control the movement of pesticide residues to undesirable locations such as water bodies, while keeping agricultural productivity high. These factors require researchers to find alternative systems to analyze the risk for surface and groundwater resources that are capable of taking into account soil and climatic conditions, and pesticide characteristics.

Use of Indicator Models to Study the Risk from Pesticides

Due to the complexity of pathways responsible for pesticide fate in the environment and the rapidly changing and inter-dependent environmental factors, scientists have used computer-based tools to analyze pesticide fate risks. This approach uses a combination of literature data, and laboratory and field measurements on pesticide adsorption, degradation, solubility and climatic data, and provides a broader and more complete picture of chemical fate by including all media (Gerrit and Bernd 1998).

These screening-type risk assessment models (CSIRO 2004; Walker and Barnes 1981) are mostly empirical and are valuable for evaluating and comparing pesticide risk in different environments and for a general risk assessment of the contamination of water resources on a large scale. The conclusions of the risk estimates allow farmers and extension workers to choose pesticides suitable for a given agro-climatic condition, correct application timing and an appropriate land use management system to minimize the environmental risk associated with pesticide applications.

Objective

The objectives of this study are to:

- Understand the patterns and practices of pesticide use in selected high-intensity agriculture areas of the central hills of Sri Lanka.

- Evaluate the possibility of using a simple computer-based risk assessment tool to better understand the potential risk of water pollution by pesticides, as an alternative to expensive and difficult pesticide monitoring and analysis in water bodies.

Materials and Methods

Description of the Study Areas

Three areas in the central hills of Sri Lanka, that are under intensive cultivation were selected for this study, namely, Nuwara Eliya, Welimada and Bandarawela, where potato is the dominant crop. The Nuwara Eliya site is located within the catchment of Gregory Lake; the site in Welimada is in the valley of Uma Oya in the Paranagama area, where the water pumping house for the Welimada Town is also located; and the Bandarawela site is near Poona Wewa (tank) between Welimada and Bandararawela near Boralanda, where the tank water is being used for domestic consumption. In addition, the potato fields were next to the water bodies, thus, leaving no buffer area between the agricultural land and the surface water body. The conditions in these areas are given in Table 1.

Table 1. Soil and environmental characteristics of the study sites.

	Nuwara Eliya (Gregory Lake)	Welimada (Uma Oya)	Bandarawela (Poona Oya)
Mean temperature ºC	15.0	19.5	19.5
Rainfall (mm/annum)	2,017	2,000	1,875
Recharging rate			
mm per year	121	121	121
Soil texture	Sandy Clay Loam	Sandy Loam	Sandy Clay
Organic matter (%)	4.0	3.0	3.4
Soil loss (k/ha)	19.6	19.6	19.5

Source: De Silva 2000; Thenabadu 1988

Farmer Survey of Pesticide Use

Information on pesticide use practices was collected through a questionnaire circulated among 69 farmers in the three study sites. Key questions asked included the type of pesticides used (commercial and chemical names), dosage, frequency of application, perceptions of dose effectiveness, and the extent of knowledge of the pollution potential and personal risk. Based on the given field information, two commonly used pesticides, Moncozeb and Propineb were selected for a study of the risks to water bodies using the Pesticides Impact Rating Index (PIRI).

Pesticide Impact Rating Model

The PIRI is a simple modeling tool that integrates the information related to the risk to surface and groundwater due to a selected chemical for selected crops in a given environment. To compute the risks, PIRI uses an extensive data set that includes climatic, soil and chemical data, as well as land use and landscape characteristics, and information related to pesticide fate in soil, water and air. Data requirements include minimum and maximum air temperature, rainfall and irrigated water, soil texture, soil organic matter content, pesticide chemical data such as adsorption partition coefficient and half-life, and pesticide application data such as frequency and dose, land use, cropping season, field cover, recharge rate, depth of water, diameter of nearest water body, distance from edge of the water body to the field or the width of the buffer zone, slope of land towards the water body, estimated average soil loss and minimum number of days from application of pesticides to first rainfall. PIRI outputs on risk are divided into six categories of risks due to mobility and toxicity, these are: very low (VL), low (L), medium high (MH), high (H), very high (VH) and extremely high (EH).

While most of the site-related PIRI data requirements are available through field measurements and literature, pesticide properties for the PIRI risk estimation for selected chemicals can be obtained-from the Farm Chemical Handbook by Meister Publishing Company (2001).

Results and Discussion

Extent of Pesticide Use

The patterns of pesticide use in Nuwara Eliya, Welimada and Bandarawela, as reported by the 69 farmers surveyed, indicated that potato farmers use fungicides extensively (Table 2).

Table 2. Pesticide use patterns in the three study areas.

Pesticide	Farmers (%)			
	Nuwara Eliya	Welimada	Bandarawela	Average
Propineb	83.4	75.0	72.0	76.8
Mancozeb	62.5	61.0	64.5	62.6
Chlorothalonil	54.0	65.2	48.0	55.7
Captan	52.4	56.5	53.0	53.9
Sulfur	50.0	45.5	56.4	50.6
Metalaxyl	48.2	50.1	53.6	50.6

More than 60 % of the farmers reported using the fungicides Mancozeb (Manganese ethyl bis dithiocarbamte polymerace complex with zinc salt) and Propineb (polymeric zinc propylene bis dithiocarbamate). On average more than 50 % of farmers use some type of chemical indicating a potential pollution problem unless good management practices are being implemented.

Pesticide Application Practices

Questions related to farmer practices of using pesticides indicated that farmers prefer to overdose and adopt higher frequencies than the recommended amounts. Forty-five percent of farmers indicated that they prefer to use more pesticides than the recommended dose of pesticides to ensure better results in crop productivity. They further indicated that they had limited knowledge about occupational exposure or the adverse effects of the pesticides that they used. Fifty-seven percent did not know the exact action of the pesticides nor were they aware that they had to use exactly the right amount of pesticides. For example, during the rainy period daily applications of fungicides were made. According to the survey some farmers highlighted the need for government support to be regular, informative and to include innovation while addressing their needs.

In addition to the survey, field observations during the study indicated that the farmers do not use appropriate mechanisms to measure the pesticide volumes that they add to the mixing tanks prior to application. For example, one common practice is to pour a fraction of the content of the bottle into the tank and judge the quantity by eye rather than measurement. Not using calibrated measuring equipment and inaccurate judgments by farmers may severely contribute to the inefficiency in pesticide use as well as contamination of water bodies.

Lack of literacy has been reported as the major reason for the misuse of pesticides and overdosing in Central Africa, which in turn results in phytotoxicity, and yield and financial losses (Youdeowei 1989). However, in Sri Lanka, the standard recommended approach of increasing awareness to improve management of pesticide use may need additional interventions to be effective because the high literacy rates prevailing in the study areas suggest that awareness is not the main issue.

It is noteworthy that Chandrasekara et al. (1985) reported similar observations on farmer perceptions and practices through a survey of pesticide use in vegetable cultivation in the central hill-country covering Nuwara Eliya, Badulla, Kandy and Matale districts. According to Chandrasekara et al. (1985), 59 % of farmers used more than the recommended quantity of pesticides in each of the districts they studied. It can be seen therefore, that even after more than 20 years, 45 % of farmers still share the same perception as regards the need and usefulness of higher doses of pesticide application, and the fact that such perceptions have endured and such practices have been followed for such a long period of time, is worth further investigation. This observation also probably calls for tighter controls over pesticide use.

Estimation of Risks

Integrated risk assessment using the PIRI model with site-specific data inputs on environmental and soil conditions for Nuwara Eliya, Welimada and Bandarawela indicates different risks for the two pesticides studied (Table 3).

Table 3. Relative risk levels and toxicity.

Pesticide	Location	Risk Ground-water	Risk Surface water	Toxicity Ground-water	Toxicity Surface water
Mancozeb	Nuwara Eliya	EH	EH	H	H
	Welimada	H	EH	M	H
	Bandarawela	H	EH	H	H
Propeneb	Nuwara Eliya	EH	EH	M	H
	Welimada	M	H	M	M
	Bandarawela	M	H	M	M

Note: EH – Extremely high; H – High; M – Medium; L- Low

According to the risk assessment, both Mancozeb and Propineb fungicides exhibited extremely high risk for groundwater and surface water contamination in Nuwara Eliya. For the Welimada and Bandarawela sites there was a high risk of groundwater pollution by Mancozeb and a medium risk by Propineb, while the surface water contamination potential was extremely high for Mancozeb and was a high risk for Propineb.

Toxicity levels of pesticides in water are derived by comparisons with their lethal dose that will kill 50 % of algae aquatic species (LC50). For surface water, Mancozeb has high toxicity levels in each area except in Welimada, where the toxicity level is medium. Propineb toxicity level is high in Nuwara Eliya surface water and medium in ground and surface waters in all other locations.

This analysis indicates the possibility of obtaining different and relative risk levels for ground and surface water for different pesticides in different soil-climatic conditions. Therefore, the method adopted in this study allows us to compare the risks to water bodies by different pesticides using limited data obtained from literature and field measurements. This work did not involve field level pesticide concentration measurements, which are very costly and require low detection limits, which often cannot be reached, as discussed in the introduction. These risk estimates can be used to explain to farmers how different soil and climatic conditions can influence the fate of the pesticides that they use and the consequent potential risk to their water supply systems. The approach also allows for the simulation of scenarios to evaluate different management methods. For example, the buffer area (area between the cropping area and surface water body) or extent of irrigation, and the management practices can be changed in the simulation. Use of PIRI as an extension tool may help to improve governance and promote best management practices for farmers.

Conclusions

Use of fungicides is very common in potato cultivation in the hill country of Sri Lanka. Propineb and Mancozeb were found to be the most common fungicides used, based on a famer survey conducted in Nuwara Eliya, Welimada and Bandarawela. The survey revealed that most farmers prefer higher doses of pesticides than recommended, and they do not use recommended mechanisms to measure pesticide volumes during the preparation of pesticide mixes. These perceptions and practices have not changed much over the years despite investments to raise awareness. This shows the necessity for additional interventions (legal and penalties) and incentives to minimize malpractice and risks to water bodies.

The common approach of water quality monitoring, to evaluate the concentrations of chemicals in water bodies, may not work for pesticides used in agriculture due to costs and lack of analytical sensitivity to identify pesticide residues. However, minute amounts of pesticides in water bodies, even below detection limits, can pose a threat to humans and biological organisms. In the absence of a proper analytical tool, the PIRI approach can be used to evaluate potential pesticide contamination of water bodies. It uses a wide range of environmental and chemical data to represent most of the environmental processes, and the results of this study demonstrated distinct variations of levels of risk and toxicity for the areas studied. Further refinement of this method could lead to a 'risk atlas' of pesticides for different soil-agro-ecological environments in Sri Lanka.

References

Abeyratna, K. W. S. D. 1985 'Potato Production in Sri Lanka', International Potato Course, IAC, Wagenigen.

Chandrasekara, A. I.; Wettasinghe, A.; Amarasiri, S. L. 1985. 'Pesticide Usage by Vegetable Farmers'. Annual Research Conference, ISTI Gannoruwa, Sri Lanka.

Commonwealth Scientific and Industrial Research Organisation (CSIRO). 2004. 'Pesticide Impact Rating Index, Mathematical and Information Science'. Adelaide, South Australia: CSIRO.

De Silva, R. P. 2000. A Simple Soil Water Balance Model to Estimate Groundwater Recharge in the Dry Zone of Sri Lanka. *Tropical Agricultural Research and Extension* 3 (2).

Farm Chemical Hand Book. 2001. Meister Publishing Company Ltd.

Gerrit, S.; Bernd, M. 1998. Ecological Fundamentals, Chemical Exposure and Biological Effects. *Ecotoxicology*, Wiley Interscience Series, USA. pp.194-195.

Thenabadu, M. 1988. 'Soil and Soil Conservation in Sri Lanka'. Sri Lanka: Natural Resources Energy and Science Authority of Sri Lanka.

Walker, A.; Barnes, A. 1981. Simulation of Herbicide Persistence in Soil: A Revised Computer Model. *Pesticide Science* 12:123–132.

Youdeowei, A. 1989. 'Provisional Report on Pesticide Management in Anglophone West Africa'. Rome, Italy: FAO.

Preliminary Groundwater Assessment and Water Quality Study in the Shallow Aquifer System in the Attanagalu Oya Basin

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Abstract

The Attanagalu Oya basin is situated between two major river basins, Kelani and Maha Oya in the Western Province of Sri Lanka, with an extent of 727 km^2. It contains four streams: Diyaeli Oya, Attanagalu Oya, Uruwala Oya and Kimbulapitiya Oya, which discharge into the Negombo Lagoon as Dandagamuwa Oya. A study was conducted in the Attanagalu Oya basin in order to assess the groundwater potential of the area and to identify the water quality of the shallow aquifer system of the basin.

The available qualitative and quantitative data on groundwater were collected and compiled, and a groundwater database was developed for the basin. The total basin area was divided into five major divisions and shallow groundwater monitoring networks were designed for each. Representative shallow dug wells were selected for the monitoring network and 100 water samples were collected from each division. Samples were analyzed for 17 physical and chemical parameters. In addition, 10 water samples were collected from surface and groundwater bodies in the paddy cultivated areas and analyzed for pesticides. Another 10 water samples from the industrialized area were analyzed for lead and 10 from urban areas were analyzed for bacteria. Based on the data collected, geochemical maps were prepared for the entire basin. These indicated that the pH values of the shallow groundwater in some parts of the Attanagalu Oya basin were very low, varying from 4 to 8.5. High electrical conductivity (EC) values were reported in the coastal area. Bacterial contamination was reported in groundwater sources in the urban areas. No pesticide contamination was detected in any of the water samples collected in paddy cultivated areas. The occurrence of lead in shallow groundwater was reported within the range of 0.01-0.02 ppm. The major aquifer types in the basin are river alluvium, coastal sand and fractured basement hard rocks. The existing northeast-southwest trending lineaments were identified as promising areas for groundwater development.

Introduction

Attanagalu Oya is considered to be a basin filled with resources. The important water uses of the Attanagalu Oya are the supply of drinking water and the maintenance of aquatic ecosystems.

Negombo Lagoon and Muturajawela Marsh are the two large aquatic ecosystems in the basin. The major environmental problems of the Attanagalu Oya basin are related to the deterioration of the water quality due to domestic, agricultural and industrial activities, specifically the uncontrolled disposal of industrial effluents (both solid and liquid) and use of agro-chemicals. Water pollution is expected in industrialized areas such as the Katunayake Industrial Processing Zone and Ekala Industrial Estate. The water quality of Negombo Lagoon has deteriorated over the past few decades, with algal growth resulting from the accumulation of nutrients.

Objectives of the Study

The main purpose of this study was to identify the water quality variation in the shallow groundwater and to make recommendations for further studies, including the long-term monitoring of variations in groundwater quality and groundwater assessment.

The Study Area

The Attanagalu Oya basin is situated between two major river basins, Kelani and Maha Oya in the Western Province of Sri Lanka with an extent of 727 km^2 (Figure 1), and has three streams, Diyaelli Oya, Attanagalu Oya and Uruwala Oya, which discharge into the Negombo Lagoon as Dandugam Oya and also through Ja-Ela. The dendritic drainage pattern can be seen in the study area. Two streams that originated from Gallanda and the Polgahagoda area join to form the Waharaka Oya. The Basnagoda Oya originated from Bewangama and flows in the southwest to northeast direction and joins Waharaka Oya to form the Attanagalu Oya. The Algama Oya joins the Attanagalu Oya close to Attanagalle Town.

The main geological formations in the basin area are: laterite, unconsolidated sand, alluvium, peat deposits and crystalline basement rocks.

Methodology

The broad set of activities in the study was to:

- Conduct a desk study to compile available data (geological, hydro-geological and geochemical), to present them on GIS maps and to identify the data gaps.
- Identify area-specific problems and undertake field visits to verify the issues and to collect data for filling the data gaps.

Field investigation was conducted in order to collect data to fill the data gaps. The total basin area of 727 km^2 was divided into five units and 100 water samples were collected from each. Another 100 water samples were collected from the problematic areas such as industrialized and extensively cultivated areas. They were tested for 17 physical and chemical parameters: appearance, temperature, turbidity, pH, electrical conductivity (EC), total hardness, total alkalinity, total dissolved solids (TDS), sodium, calcium, potassium and magnesium ions, total iron, fluoride, sulphate, chloride, salinity and nitrate, and the results were compared with

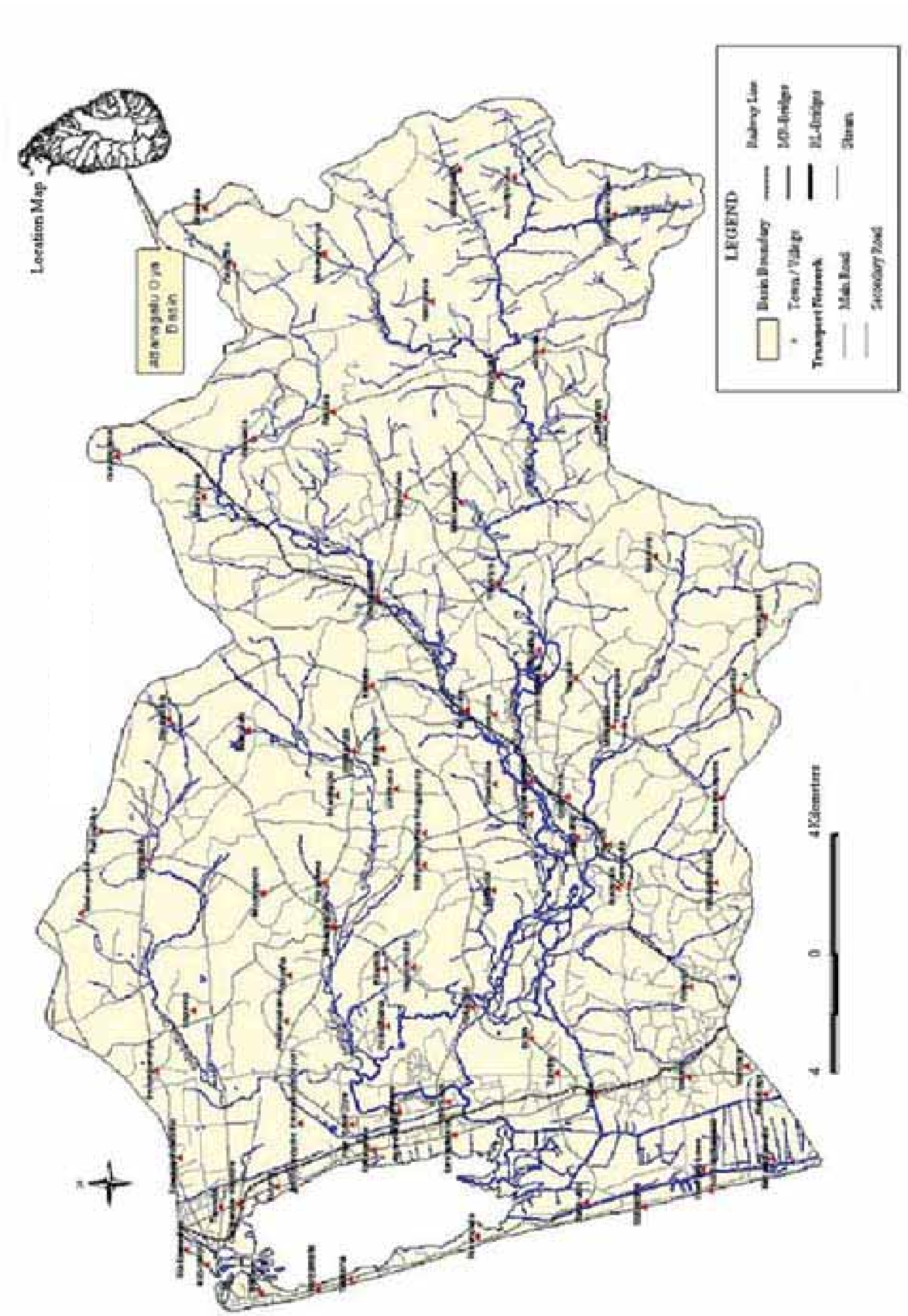


Figure 1. Map of the Attanagalu Oya Basin.

the Sri Lankan drinking water standards. In addition, 10 water samples were collected from extensively cultivated areas and analyzed for pesticides; 10 water samples were collected from industrialized areas and analyzed for lead; and 10 water samples were collected from the urban areas of the basin and analyzed for bacteria. The data were used to prepare geochemical maps.

Aquifer Types in the Basin

The major aquifer types identified in the Attanagalu Oya basin are: lateritic, alluvial, coastal sand and fractured crystalline basement aquifers.

Lateritic Aquifer

The major lateritic formations can be identified in Ragama, Gampaha, Veyangoda, Andiambalama, Naiwela, Kimbulapitiya, Ganemulla and Katana. In Ragama, the formations indicate that part of the rainwater falling on the area drains away rapidly along short–lived surface streams, gullies, foot-paths and roads, but most of it percolates downwards, eventually seeping into the marshes and streams between the laterite hills. The water bearing lateritic formation behaves as a water table aquifer, oscillating the water table in a wide range of about 7 meters at the top of the hills and 3 meters on the slopes. The best sites for wells are, therefore, the valley edges in this particular area. The well-yields of the lateritic aquifer mainly depend on the permeability of the formation. In areas where the laterite fills with kaolin, the expected well-yields would be very poor. Wells in those areas may become dry during the dry period of the year.

Alluvial Aquifer

Alluviums are one of the largest carriers of groundwater among the sedimentary formations. Alluvium can be found in the major river valleys and may vary from 8-10 meters in thickness and laterally for several hundreds of meters on either side of the riverbeds. The alluvial beds may be composed of sand, clay or gravel, and form high potential aquifers. The alluvium beds in the Attanagalu Oya and other rivers could be considered as water table aquifer systems. The wells located in that aquifer type indicate a very shallow groundwater table varying from 1.0 meters to 2.0 meters.

Beach Sand

The unconsolidated sand belt runs along the coastal belt, especially from Ja-Ela, Seeduwa and Katunayake up to Negombo. This sand belt is well developed in the Katunayake and Seeduwa areas. The Katunayake International Airport and the Katunayake Export Processing Zone fall within this sand belt and extract considerable amounts of water from this sandy aquifer system. In the Katunayake Export Processing Zone, 98 factories are established and part of their water requirement is supplied by the surface water from the Dandugam Oya and the rest is supplied by groundwater from 44 shallow and deep tubewells. The quantity of water that was recommended to be extracted from these tubewells was estimated at 3,000 m^3 per day. The tourist hotels in the Katunayake area and most of the private establishments located along the coastal belt also extract groundwater from this aquifer. This aquifer was subjected to pollution due to domestic, industrial and agricultural activities. Katunayaka International Airport also extracts water from shallow tubewells constructed in this coastal sandy aquifer.

Fractured Crystalline Basement Aquifer

The unweathered crystalline rocks by their nature are relatively impervious and non-porous. Where joints and fissures are concentrated in zones, as in fault zones, then the permeability of the system is increased to important proportions. There is, therefore, no continuous body of groundwater with a single water table in these rocks. The presence of major lineaments is a good indication of the existence of a fracture in the basement rocks. The major lineaments in the Attanagalu Oya basin are directed to northeast-southwest (NE-SW), east norteast-west southwest (ENE-WSW), east-west (E-W) and northwest-southeast (NW-SE). The NW-SE lineaments are strike valleys running parallel to the strike of the basement rocks. A major lineament, striking WNW-ENE direction, runs through Makewita, Kalagedihena up to Attanagalla. A similar type of lineament system runs across Minuwangoda and Nittambuwa. The areas where major lineaments cross each other are considered to be promising areas for groundwater development.

Issues Identified within the Basin

The Divisional Secretariat (DS) Divisions, Pradeshiya Sabas and other relevant organizations in the basin area were contacted and the data related to water issues were collected.

The areas surrounded by Negombo Lagoon such as Talahena, Peruwa and another nine Grama Niladhari Divisions (GNDs) have insufficient water for drinking purposes. Pipe-borne water is available in the area but the supply is inadequate. Therefore, water scarcity exists in these areas. The total number of families that do not have sufficient water facilities in the area is 13,438 (Census 2004). The main water sources used by the people are dug wells, tubewells and their own tap lines.

The area of Meerigama Pradeshiya Sabha is 189 km^2 and the population is 1,43,741. Of these a total of 4,500 families do not have proper water facilities (Census 2004). Due to the over extraction of water, the people in the surrounding area are faced with water problems even when there is a slight dry spell. There is also considerable pollution in the natural stream due to the emission of effluents from rubber factories and coconut mills.

Water pollution in Negombo Lagoon is also a problem because the boat building industries dispose of their effluents into the lagoon, and sewage and other wastes from many houses in the area are also diverted there. Most of the drainage in Negombo Town is also diverted into the lagoon.

Dumping of solid wastes such as silage, plastics, metal cuttings and tailings are common practices and have become a growing problem in Sri Lanka. This is further aggravated by the absence of a proper waste management system. The inevitable consequences of the practice of solid waste disposal in landfills are gas and leachate generation due primarily to microbiological composition, climatic conditions, refuse characteristics and land filling operations. These can impact on surface waters and on groundwater, which is often a source of drinking water. In the solid waste dumping areas of Katana and Negombo DS Divisions, the concentrations of heavy metals (lead, chromium and copper) in shallow groundwater in dumping areas are reported to be high (Water Resources Research in Sri Lanka 2004).

Results and Discussion: Hydro-geochemical Maps

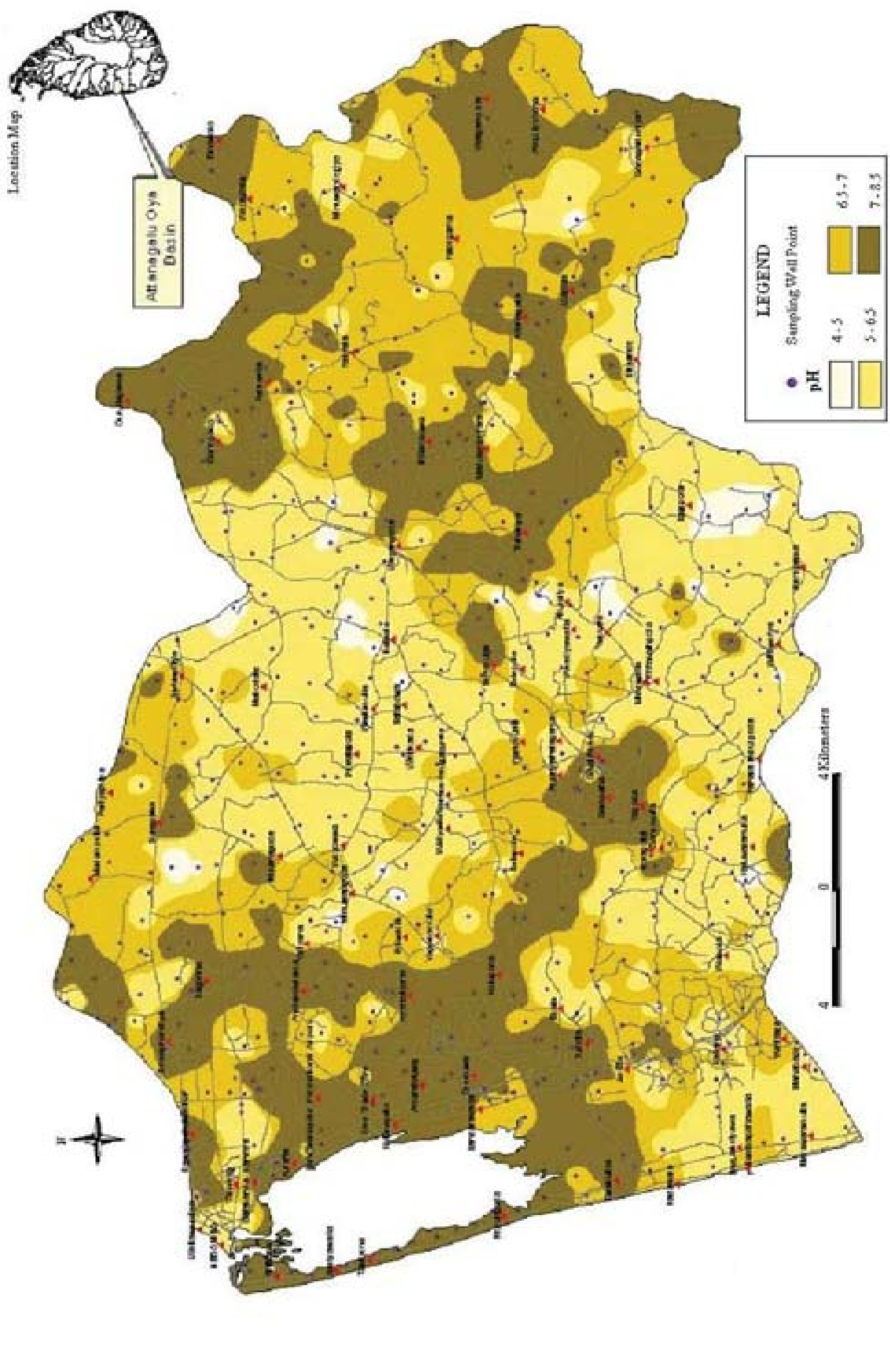
Using the analytical data of 600 water samples of the Attanagalu Oya basin, geochemical maps were prepared for pH, iron, salinity, total hardness, sodium, potassium and EC, and results were compared to Sri Lankan drinking water standards. Different zones were identified based on these maps.

In most natural waters the pH value is dependent on the carbon dioxide-carbonate-bicarbonate equilibrium, and the presence of phosphates, silicates, fluorides and other salts in dissociated form may affect the pH. Chemical changes such as reduction and oxidation and decomposition of organic matter may also change the pH in groundwater. The shallow groundwater in zones 1 and 2 is acidic (Figure 2), which could be a serious problem. The zones with very low pH values (pH 4-5) are located in the central and southern part of the basin. However, the pH values of shallow groundwater in the western part of the basin fall into the zones 3 and 4, with pH values of 6-8.5, which is acceptable for drinking water.

For EC, the majority of the area falls into zone 1 with an EC of 5-250 μS/cm but high concentrations were detected in the western coastal zone area (Figure 3). This area also has the highest salinity values and hardness. The map of sodium concentration of shallow groundwater in the basin area was based on eight zones. The majority of the areas fall into zones 1 and 2 (1-20 mg/l and 20-40 mg/l), but high values were recorded in the western part of the basin. For potassium, the majority of the area falls into zone 1 (0.3-5.0 mg/l) indicating a low level of potassium contamination in the groundwater. The southern and eastern part of the basin area falls into fluoride zone 1 (0-0.2 mg/l), while the western, northern and some of the central areas fall into zone 2 (0.2-0.4 mg/l). Patches of zone 4 (0.6-0.7 mg/l) can be seen in the central and western part of the basin. For iron, most of the area of the basin falls on the range 0.0-0.3 mg/l (zone 1) and 0.3-1.0 mg/l (zone 2). Higher values are reported in the south-western part of the basin. For lead, values ranged from 0.01 to 0.02 ppm, which indicates that lead pollution of groundwater is not a problem in the basin.

Considering all the hydro-geochemical maps, the promising areas for groundwater development were identified as indicated in Figure 4.

Figure 2. Map of pH variation.



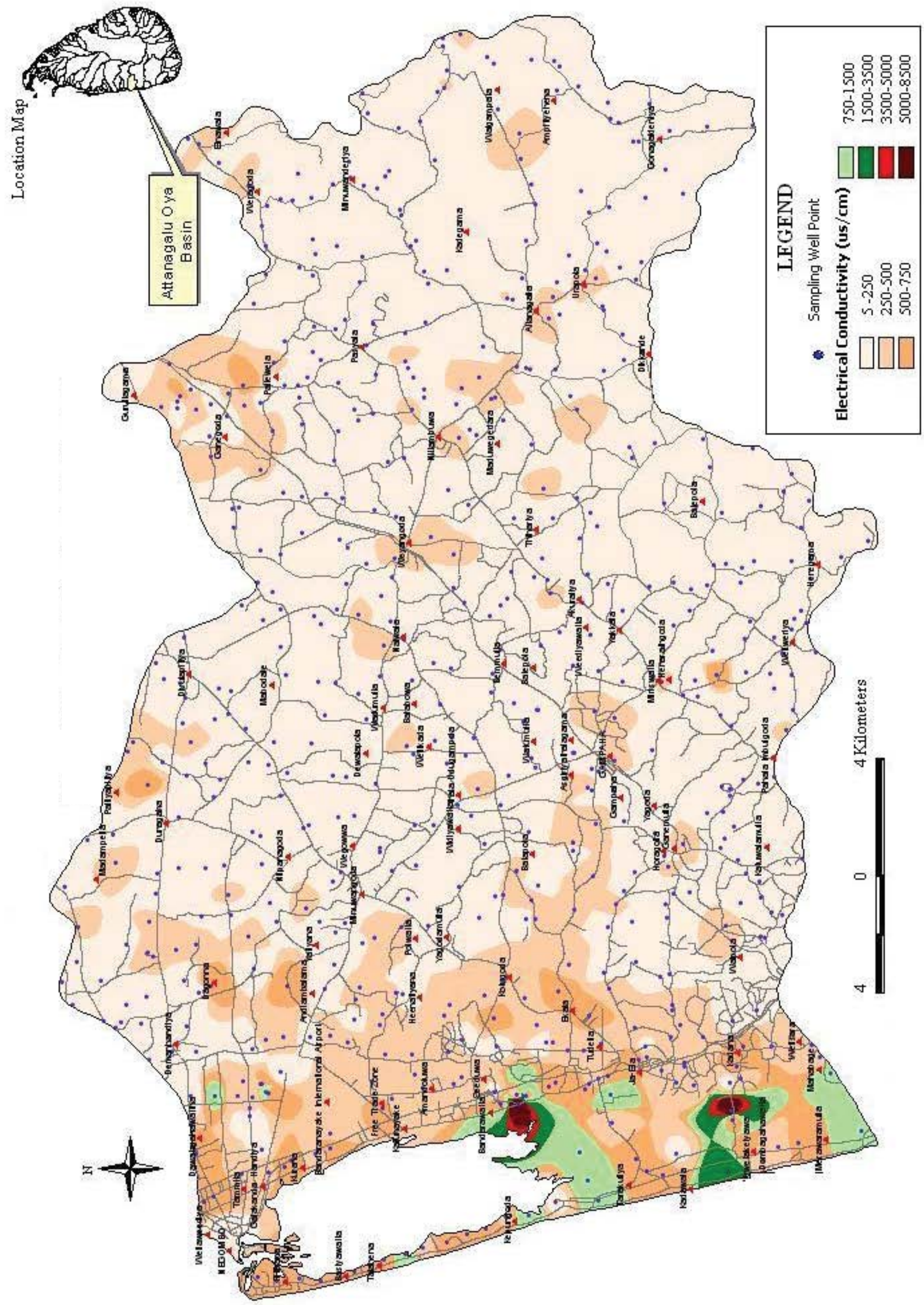
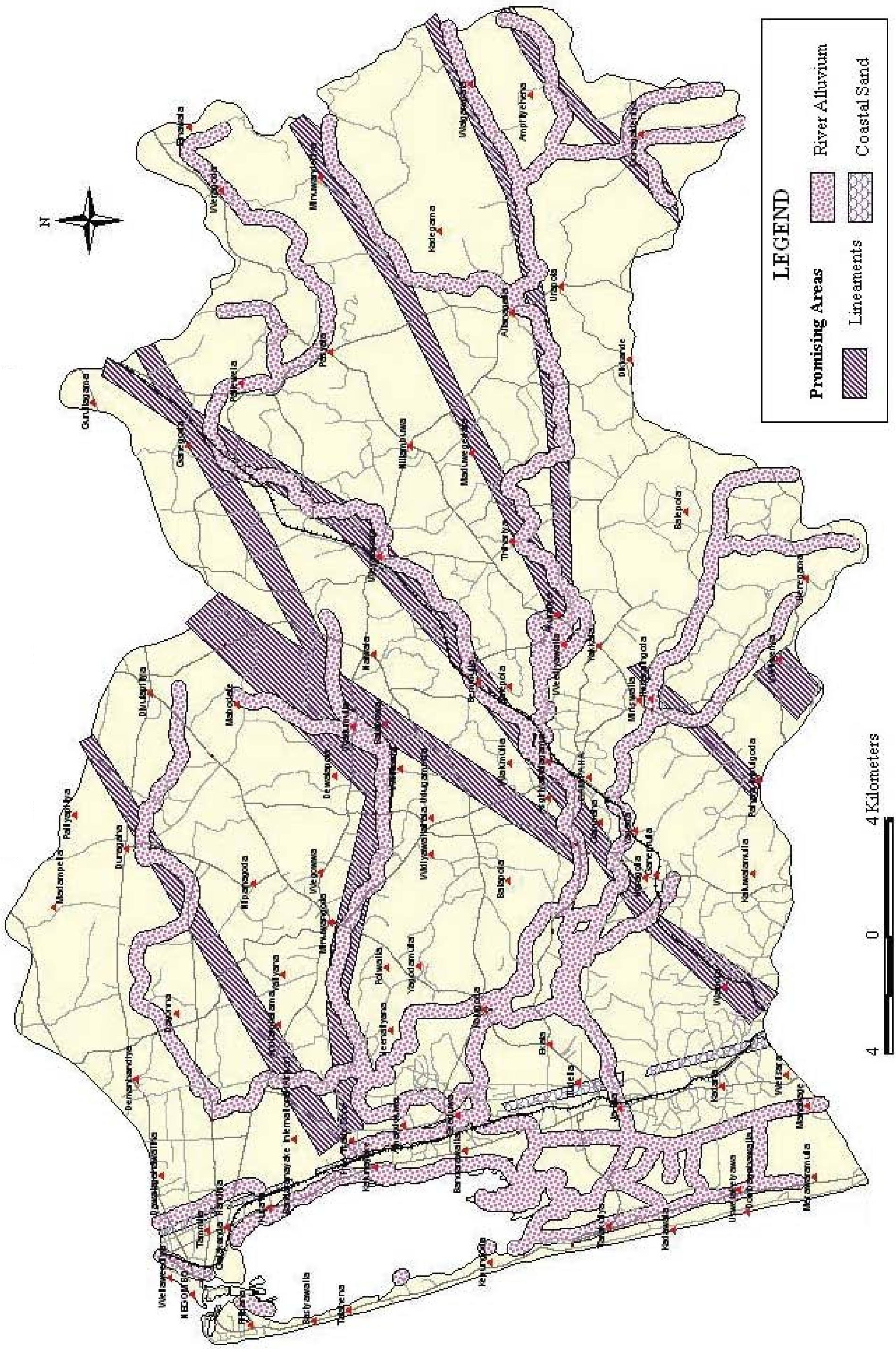


Figure 3. Map of electrical conductivity variation.

Figure 4. Map of promising areas for groundwater.



Conclusion

Pollution of groundwater and surface water was found to be mainly due to domestic, industrial and agricultural activities. The wells in many urban areas suffered from bacteriological pollution, which was clearly observed in the urban areas of Ekala, Ja Ela, Negombo, Wattala and Gampaha.

The data collected from DS Divisions, Pradeshiya Sabhas and other relevant agencies indicated that the dug wells are the main source of water for households in the basin and a considerable number of families have no proper water sources for drinking purposes. This was reported in the Meerigama, Attanagalla, Gampaha and Negombo DS Divisions and the Pradeshiya Sabha Areas of Meerigama and Katana.

The pH values of shallow groundwater in the basin show uneven distribution throughout the basin. Shallow water becomes acidic in some parts of Naiwala, Minuwangoda, Ekala, Walpola, Henegama, Weliweriya, Pahala Imbulgoda, Weediyawatta and Henarathgoda, but in the rest of the area the pH values are within the drinking water standards. It is recommended to design a proper monitoring network to monitor pH variation of groundwater over a long period including both dry and wet seasons.

High salinity and iron concentrations were reported in the shallow groundwater along the coastal strip. Water quality of shallow groundwater in the rest of the area is suitable for drinking purposes.

Using the existing aquifer systems an additional amount of water could be supplied to the water supply schemes in Gampaha, Veyangoda, Raddoluwa, Bataleeya, Minuwangoda, Ja-Ela and Divulapitiya.

Conjunctive use of groundwater and surface water and recycling of water in the industries would be one of the major water conservation methods in the industrial sector.

References

Central Environmental Authority. 1995. ‘Man and Environment.’

Cooray, P. G. 1984. ‘Geology of Ceylon.’

Population and Housing Census, Gampaha. 2004.

Water Resources Research in Sri Lanka. 2004. Symposium Proceeding of the Water Professional’s Day.

Wijesekara, R. S.; Perera, A. P. G. R. L.; Wijekoon, D. V. K.; Kudahetty, C. 2005. ‘Preliminary Groundwater Assessment Attanagalu Oya Basin’. Sri Lanka: Water Resources Board.

Household Water Security through Stored Rainwater and Consumer Acceptability: A Case Study of the Anuradhapura District

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Abstract

Rainwater harvesting has increased in popularity in Sri Lanka over the past two decades due to the number of water supply projects funded by the government and non-governmental organizations (NGOs). The stored rainwater can provide accessible, reliable, timely and adequate supplies of water to households but there are uncertainties as to safety, in terms of water quality, and consumer acceptability. A study was, therefore, conducted in the Anuradhapura District, in the dry zone, to assess consumer acceptability of stored rainwater for household purposes and to conduct rainwater quality tests in a laboratory.

The majority of households in Anuradhapura meet their drinking water requirements from protected wells (59.6 %). Prior to the project, people greatly preferred open wells as a source of domestic water, followed by tubewells, because they believed that water in open wells is of good quality and drinkable. However, stored rainwater has become the priority source now, especially through roof rainwater harvesting (RRWH), which is used during the dry periods. The study revealed that more than 85 % of households use stored rainwater for drinking although some have concerns over the quality and only drink it after boiling. The easy accessibility of water and the assurance by the project team that it is of good quality are the main reasons that people are willing to drink it. The acceptability of stored rainwater for consumption was very high in water-scarce areas and with the increasing distance to the nearest and alternative sources of good-quality water. Of those who felt that they had adequate water, 84 % of the sample households found it adequate in the wet season but only 21 % in the dry season.

Water quality analysis revealed that the chemical and physical quality of stored rainwater is within the acceptable range with respect to Sri Lankan Standards, SLS: 614, for potable water quality (SLIS 1983). Other domestic water sources exceeded standards for electrical conductivity, total alkalinity, hardness, ammonium nitrogen, fluorides and total iron. However, stored rainwater was of lower biological quality than other domestic water sources.

Introduction

Rainwater harvesting has increased in popularity in Sri Lanka over the past two decades as a result of various projects. In most cases, roof rainwater harvesting (RRWH) has been undertaken, mainly for reasons of convenience for the households, in areas where the planned supply is unreliable or where local water sources dry up for a part of the year. However, it has also been introduced in places as part of an integrated water supply system, where it may be used as the sole water source for a community or household.

A feasibility study of RRWH revealed that it could be successfully practiced in all parts of Sri Lanka (Hapugoda 1995; Chandrapala 1996; Rajkuma 1998). It is a technology that is flexible and adaptable to a very wide variety of conditions, being used in the richest and the poorest societies, and in the wettest and the driest areas of the country. As a result, various different types of rainwater harvesting systems have been adopted by rural people for domestic use in almost all parts of Sri Lanka (Ariyabandu 1998). The attractive benefits of rainwater harvesting are the low cost, simple design and construction technology, its independence from a central system, accessibility and easy maintenance.

In typical RRWH, rainwater from the house roof is collected in a storage vessel or tank for use during periods of scarcity. Usually these systems are designed to support the drinking and cooking needs of the family, and also in rare situations for home gardening. Such a system usually comprises of the roof, a storage tank and guttering to transport the water from the roof to the storage tank. A first flush system to divert the dirty water that contains roof debris collected during non-rainy periods and a filter unit to remove debris and contaminants before water enters the storage tank are also required.

Although rainwater harvesting has been accepted as an alternative rural water supply source in Sri Lanka, and can provide accessible, reliable, timely and adequate water, fewer than 10 % of households that have acquired RRWH systems consume the water (Ariyabandu and Aheeyar 2000). Consumers have concerns about safety (rainwater quality) and hence, there are issues over consumer acceptability in RRWH systems. One reason for this is the users' perceptions of quality during the storage period. As a result, the prospect of rainwater harvesting in Sri Lanka would primarily depend on consumer attitudes and user perceptions of roof water as a drinkable domestic source. In addition, Heijen and Mansur (1998) investigated the improvement in water security of the RRWH beneficiary community and showed that it remains low due to a lack of awareness and poor recognition of the technology by policymakers. Several initiatives have been made by NGOs to change these misconceptions and the situation is changing rapidly.

In general, the safety of rainwater can be measured at a household level by people's perception and in the laboratory by absolute measurements. It is particularly important to study changes in rainwater quality during the storage period inside a tank under dry zone conditions. In the past few years, many studies have been conducted to improve techniques of RRWH but less emphasis has been given to consumer attitudes and the perceptions regarding domestic consumption and quality of harvested rainwater. This study attempts to assess the quality of stored rainwater through laboratory analysis and by evaluating consumer preference through a questionnaire circulated in the Anuradhapura District, in order to determine the suitability of stored rainwater for domestic use.

Materials and Methods

The Study Area

The study was conducted in Anuradhapura District, which occupies a significant portion of the dry zone and where the dry period is experienced from May to September. It has a population of 746,756 in 22 District Secretariat (DS) Divisions. The majority of households (59.6 %) obtain drinking water from protected wells, 13.7 % from tubewells and the rest use water from unprotected wells, pipe-borne water, tanks and reservoirs (Census of Population and Housing, Anuradhapura, 2001). Agriculture is the main income generating activity for 75 % of the total district population (Census of Population and Housing, Anuradhapura, 2001). By the end of 2005, more than 2,800 rainwater tanks had been constructed by the National Water Supply and Drainage Board (NWSDB), Anuradhapura, under an Asian Development Bank (ABD) project. In addition, several other organizations, including CARE, Rajarata and Navodaya had also contributed to the use of rainwater in Anuradhapura.

Sampling and Questionnaire Survey

The 2,800 rainwater harvesting systems constructed by the NWSDB in 10 DS divisions in were selected as the study population, within which 60 households (10 from each DS division) were randomly selected for a questionnaire survey. All the survey data were analyzed using SPSS statistical package.

Water Sample Analysis

For water quality testing, 10 stored rainwater samples were collected on a weekly basis for a period of 2 months from November to December 2005, using a stratified sampling technique. Simultaneously, water samples from the other main water sources of the selected households were also collected once for water quality analysis. All water samples were analyzed for important physical, chemical and biological parameters for drinking water at the regional laboratory of NWSDB in Anuradhapura. The results were also analyzed using SPSS.

Results

Use of Multiple Water Sources

The rainwater user communities do not depend totally on stored rainwater for domestic purposes. In the dry zone, communities use multiple sources to achieve water security (Ariyabandu 2001). Table 1 indicates six priority water sources available in the area. Most of the people preferred to use (priority 1) open wells because they believe that water in open wells is better in quality and potable.

Table 1. Water availability on priority basis in the study area.

Source	Percentage of households*		
	Priority 1	Priority 2	Priority 3
Open wells	63	3	05
Tubewells	33	2	02
Pipe-borne water	2	0	0
Lake	0	50	08
River	2	0	05
Rainwater harvesting	0	45	80

Note: * Multiple answers

Table 2 shows that more than 50 % of households fetch water for drinking purposes from sources that are close to the home, but according to the findings of the survey, the quality and availability of water changes with the season. Based on the perception of high water quality in those sources, respondents were not entirely in favor of rainwater, but the introduction of RRWH has significantly reduced travel time for fetching water and increased the availability of good quality water at the doorstep of households, thus improving the quality of rural life.

Table 2. Travel distance to water sources before introduction of RRWH.

Purpose	Percentage of households (%)			
	<100 m	100-500 m	500-1,000 m	>1,000 m
Drinking	50	39	6	5
Cooking	52	39	6	3
Bathing	27	29	26	18

Water Quality Perceptions and Drinking Water Priorities

According to the survey data, before RRWH units were introduced, most of the households fulfilled their domestic water requirements from open wells (priority 1) throughout the year (Table 1). However, after introducing the RRWH units, their priority for available water sources changed, particularly in the dry periods, with many now preferring rainwater, as shown in Table 3. In almost all the households with RRWH units, rainwater was used in combination with other sources during certain periods of the year. However, during the dry periods the most crucial water source for 71 % of the households has become stored rainwater (Table 3).

Table 3. Prioritization of water source by users during dry periods.

Source	Percentage of households*		
	Priority 1	Priority 2	Priority 3
Open wells	24	40	10
Tubewells	3	32	5
Pipe-borne water	2	0	0
Lake	0	8	62
River	0	0	10
Rainwater harvesting	71	20	13

Note: * Multiple answers

According to the survey results shown in Table 4, more than 85 % of households use stored rainwater for drinking. Easy accessibility of water, cleanliness and quality assurance by project staff are the main reasons for this. They also mentioned depletion of water levels in drinking wells and high concentrations of fluoride in groundwater. The reasons for not drinking it were mainly focused on quality and palatability.

Table 4. Reasons for drinking or not drinking stored rainwater.

Reason	Households* (%)
Drinking	
Long distance to the nearest water source	6
Easy access of water	40
Cleanliness	39
Quality assurance by project partners	11
Hygienic and healthy	4
Not drinking	
Cement taste in water	13
Easy accessibility of good-quality water	20
Lack of tank cover or filter	40
Unclean roof surface	14
Hygienically unhealthy	13

Note: *Multiple answers

One of the primary objectives of RRWH systems is to provide an assured supply of quality water at the homestead. Perceptions about the quality of rainwater are summarized in Table 5, which shows that more than 62 % of the respondents stated that the quality of rainwater was good and suitable for drinking without boiling.

Table 5. Quality perception of harvested rainwater.

Perception	Households* (%)
Quality of water is poor and not good for drinking	10
Quality of water is poor but can be used for drinking after boiling	3
Quality of water is good but cannot be used for drinking without boiling	20
Quality of water is good and can be used for drinking without boiling	62
No answer	5

Note: *Multiple answers

Status of Rainwater Harvesting Units

There are a number of houses that use RRWH units without proper gutters, down pipes, filters and tank lids. All these deviations from the standard method for a RRWH system affect the quality of stored water. Collection of water depends on two main factors: intensity of rainfall and roof coverage (the area installed with a gutter to collect the runoff). In most houses the roof coverage for harvesting is only between 25-50 %, which may affect water collection in dry periods because occasional rains during inter-monsoonal periods do not fill the tank to its capacity.

Although the project partners recognized concrete lids as standard, several other types of tank lids such as wood, aluminum and plastic have also been used. A large number of households do not seal the tank opening securely, which leads to mosquito breeding. In addition, about 30 % of households practiced rainwater harvesting without a filter. This can support mosquito breeding and contamination of the water with external materials such as leaf litter, animal and birds excreta, and can even lead to the growth of small fauna and flora given the increased nutrient content of the water. More than 50 % of beneficiaries of the RRWH system responded that roof litter was the main problem for water quality deterioration during the storage period.

Use of Rainwater for Animal Husbandry and Home Gardening

The total water requirement for animals and home gardening is met with other sources of water and harvested rainwater is rarely used unless the household rears one or two animals. Stored water is never used for home gardening mainly because the tank capacity is insufficient to meet the water requirement for such a purpose.

Adequacy of Stored Rainwater

Storage tanks of 5 m^3 are usually recommended to meet the water demand for a 50-day dry period, based on a designed parameter of 20 liters per person per day for a family of five members (Hapugoda 1995). Water demand can vary between 25 and 30 liters per person per day for all domestic purposes depending on the season and availability of water (Ariyabandu and Aheeyar 2000). However, households have often complained about the inadequacy of stored rainwater capacity for dry periods (Table 6).

Table 6. Adequacy of rainwater storage tank as a supplementary water source.

Level of adequacy	Season	
	Wet (%)	Dry (%)
More than adequate	10	0
Adequate	84	21
Satisfactory	6	19
Not adequate	0	60

Those who responded positively to the adequacy of the stored rainwater had sufficient water due to judicious water management and control. Those households that used water during the wet season for domestic activities understood the water availability in the tank. In the dry season, water was mainly used for drinking and also for cooking particular foods, for example, such households believe that the lentil curry can be cooked well with rainwater.

Maintenance of Rainwater Harvesting Units

Regular maintenance of RRWH units is important to obtain good quality water as well as to ensure the sustainability of the tank. More than 60 % of respondents clean the system at least once a year but 6 % do not clean the system at all. Most of the respondents have doubts about the consistency of rainfall. Moreover, people hesitate to clean the system in view of household water security and in case the rains are delayed. The respondents were asked about the problems encountered in RRWH and raised several issues that are summarized in Table 7.

Table 7. The problems encountered with the practice of RRWH.

Problems	Households (%)
Maintenance difficulties	37
Technological problems	30
Insects vector problems	30
No problems	3

Most of the households stated that the maintenance of the system was difficult. Another major reason was technical problems during construction, partly because not all the components were provided with the unit under the subsidy (for instance, gutters, down pipes, first flush device). Later, filters and tank lids were incorporated into the subsidy under the Asian Development Bank (ADB) project. In the case of the components that were not covered by the subsidy, the beneficiaries were requested to install such parts using their resources. The ability to purchase these materials depends on the financial capability of households. The absence of lids and filters has allowed harmful matter to enter into the tank creating health problems for poor people and opportunities for insect vectors to breed.

Water Quality Analysis

According to the results of stored rainwater sample analysis, most of the water quality parameters are within the acceptable range with respect to potable water quality standards for Sri Lanka (Sri Lankan Standards; 614, 1983). These include color, turbidity, electrical conductivity (EC), total alkalinity, nitrate, nitrite, chlorides, sulphate, phosphate, total iron, biochemical oxygen demand (BOD), fluoride and Escherichia Coli (E. Coli).

Ammonium nitrogen, pH and total coliform were above acceptable limits in a number of samples. The pH levels range from 8.25-10.71 (Figure 1), which may be caused by rehydration of cement mortar in the tank. Normally, rainwater becomes acidic when it mixes with atmospheric carbon dioxide, producing carbonic acid, which could increase corrosion in the tank. In addition, during thunderstorms, large amounts of nitrogen are oxidized to N_2O_5 and its union with rainwater produces nitric acid. Ammonium nitrogen concentration values vary from 0-0.59 mg/l and are higher than the Sri Lankan Standards 614 of 0.15 mg/l (Figure 2). It can be found in storage tanks because of the biological decomposition of protein substances such as bird droppings and dead insects from roofs and gutters, and the RRWH system needs to have measures to prevent such contamination.

Figure 1. Variation of pH values of stored RRWH units during sample periods.

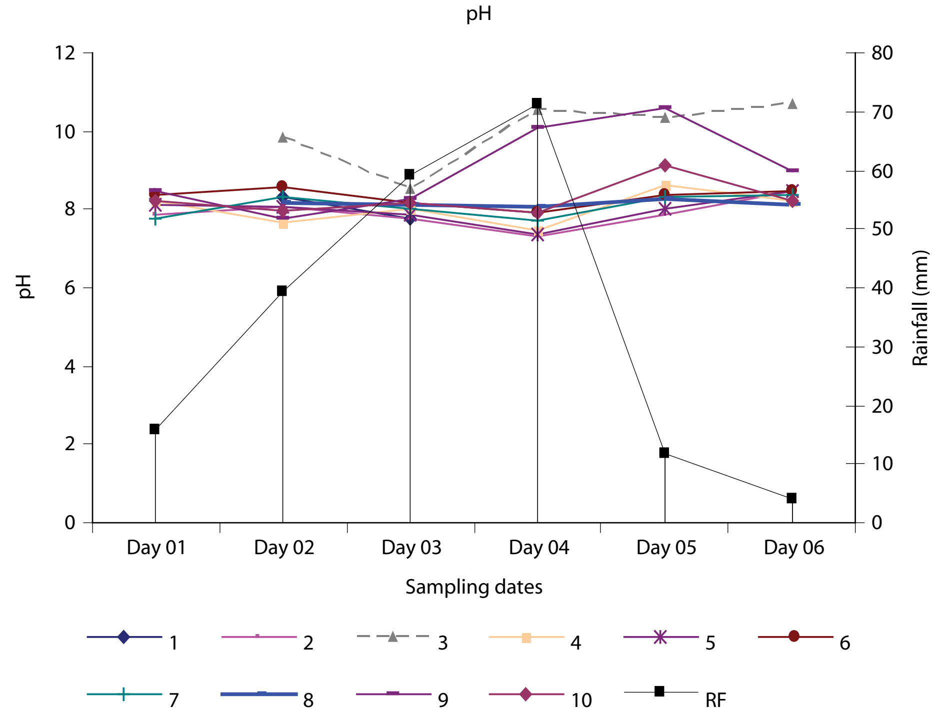
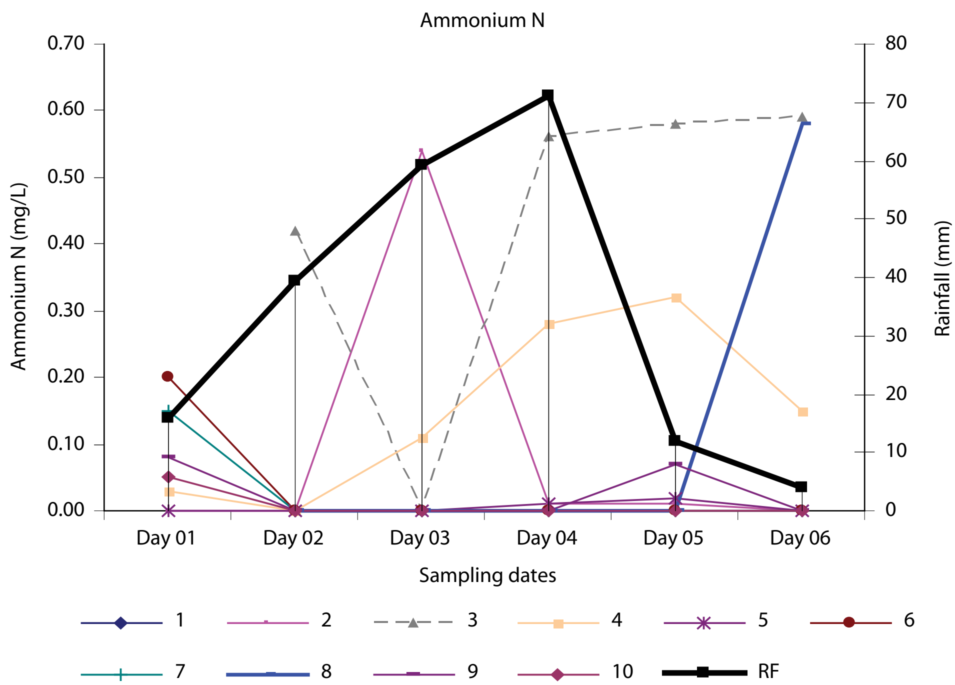
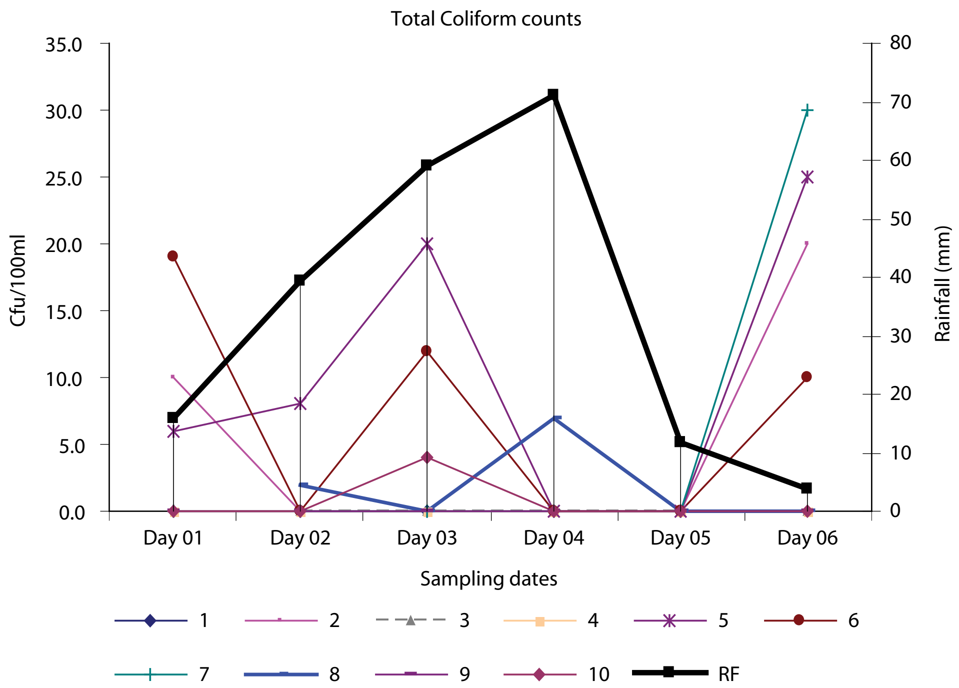


Figure 2. Variation of ammonium nitrogen values of stored RRWH units during sample periods.



Total coliform counts ranged from 0 to 30 (Figure 3) but the permissible level, according to the Sri Lankan Standard 614, is 10. The bacteriological quality of the stored rainwater, based on the faecal coliform count, does not meet the SLS or the WHO standards either (SLIS, 1983; WHO, 2008). A similar result was obtained in a study carried out by Ariyananda (2001). Coliform bacteria can attach to some of the tiny clay particles dispersed in the atmosphere, which mix with raindrops and enter the tank during rainy periods (UNEP 2000). Bird and animal excreta on the roof will add to the total coliform count as they will be washed into the tank. These hypotheses are supported by the fact that those households with the highest coliform and faecal coliform counts did not have filters or lids.

Figure 3. Variation of total coliform counts of stored RRWH units during sample periods.



For the other main water sources sampled, colour, turbidity, EC, nitrogen, nitrite, chloride, sulfate, phosphate, BOD and E. Coli were within an acceptable range. Observed pH, total alkalinity, fluoride, total Coliform and hardness values were higher than the desirable level of Sri Lankan standards but were within the acceptance level. The ammonium nitrogen concentration obtained was higher than the permissible level in potable water.

Conclusions

In most cases where RRWH is practiced, only 50 % of the roof area is utilized for the collection of rainwater due to the poor arrangement of gutters for water collection. This indicates that there is potential to improve the total water quantity harvested at each household.

Although the priority water source before the introduction of RRWH was open wells, harvested rainwater has become the priority source now, especially during dry periods. The perceptions and attitudes of people towards the use of stored rainwater for drinking have also changed. From the total sampled population, 85 % use rainwater for drinking although some have concerns about the quality and use it only after boiling. The acceptability of rainwater for consumption was very high in water-scarce areas and such acceptability improves with increasing distance to the nearest and alternative source of good quality water.

The stored water meets the Sri Lankan potable water quality standard in terms of chemical and physical parameters but not biological parameters since the total coliform count exceeded the permissible standards. Therefore, the boiling of this water should be recommended before drinking.

The quality of the main water sources are within the Sri Lankan potable water quality standards except for EC, total alkalinity, hardness, ammonium nitrogen, fluorides and total iron, which are higher than the stored rainwater.

The biological quality of stored rainwater is below that of the main water sources. The use of proper structural devices, first flushing and periodic treatment (e.g., chlorination) of stored rainwater may improve its quality and could increase user-confidence in this alternative water source.

Acknowledgements

The study was supported by a grant from the CARP, Sri Lanka. The authors wish to thank Mr. Kokila Ranasinghe, Assistant General Manager and Mrs. Subashini, Regional Chemist, NWSDB, Anuradhapura for their valuable support given for this study.

References

Ariyabandu, R. de S.; Aheeyar, M. M. M. 2000. 'Evaluation the Effectiveness of Rainwater as a Domestic Water Source in Rural Sri Lanka'. Report prepared for the Lanka Rainwater Harvesting Forum, unpublished.

Ariyabandu, R. de S. 1998. 'Study of Existing Rainwater Harvesting Technology'. Report prepared for the Lanka Rainwater Harvesting Forum, unpublished.

Ariyabandu, R. de S. 2001. 'Household Water Security Using Rainwater Harvesting'. Domestic Roof-water Harvesting Workshop, IIT Delhi, India.

Ariyananda, T. 2001. 'Quality of Collected Rainwater in Relation to Household Water Security'. Domestic Roof-water Harvesting Workshop, IIT Delhi, India.

Chandrapala, L. 1996. 'Long-term Trends of Rainfall and Temperature in Sri Lanka'. Climate Variability and Agriculture. Narosa Publishing House, India.

Department of Census and Statistics. 2001. Census of Population and Housing, Anuradhapura, Sri Lanka.

Hapugoda, K. D. 1995. 'Action Research Study on Rainwater Harvesting'. Community Water Supply and Sanitation Project (CWSSP), Colombo, Sri Lanka.

Heijen, H.; Mansur, U. 1998. Rainwater Harvesting in the Community Water Supply and Sanitation Project. In: *Proceedings of the Symposium on Rainwater Harvesting for Water Security*. Lanka Rainwater Harvesting Forum, Sri Lanka.

Rajkuma, S. G. G. 1998. Rainwater Harvesting for Domestic Use. In: *Proceedings of the Symposium on Rainwater Harvesting for Water Security*. Lanka Rainwater Harvesting Forum, Sri Lanka.

SLIS (Sri Lanka Institute of Standards). 1983. 'Specification for Potable Water Quality', SLS-614. Sri Lanka. Sri Lanka Institute of Standards.

UNEP (United Nations Environmental Programme). 2000. 'What Must be Considered from Quality and Health Aspects in Utilizing Rainwater'. Division of Technology Industry and Economics, United Nations Environmental Programme (UNEP). Retrieved January15, 2008. www.unep.or.jp/ietc/publications/urban/urbaneny-2/5.asp

Wickramasighe, R.; De Silva, R. P. 2004. 'Simulation and Modeling for Improving Water Availability through Rainwater Harvesting'. Seventh Symposium of Rainwater Harvesting for Urban Areas. Colombo, Sri Lanka: LRWHF.

WHO (World Health Organization). 2008. 'Guidelines for Drinking-water Quality', Vol. 1, 3rd Edition Incorporating 1st and 2nd Addenda. Geneva, Switzerland: World Health Organization.www.who.int/water sanitation health/dwq/gdwq3rev/en/

Observed and Projected Climatic Changes, Their Impacts and Adaptation Options for Sri Lanka: A Review

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Abstract

Climate is changing world-wide, and the science community in Sri Lanka has come up with ample evidence to suggest that the country's climate has already changed. During 1961-1990 the country's mean air temperature increased by 0.016 ^{0}C per year, and the mean annual rainfall decreased by 144 mm (7 %) compared to the period 1931-1960. In addition, mean annual daytime maximum and mean annual night-time minimum air temperatures increased. However, the bigger question of national importance is what Sri Lanka's climate will look like in 50 or 100 years and how prepared is the country to face it. Apart from the Intergovernmental Panel on Climate Change (IPCC) projections at the coarse global scale, few studies have attempted to project future climate scenarios for Sri Lanka and to identify climate change impacts on agriculture, water resources, the sea level, the plantation sector, the economy and health. Vulnerability and adaptation to climate change are the least studied areas. This paper reviews the status of climate change research and activities in Sri Lanka with respect to future climate projections, impacts, climate change mitigation and the country's ability to adapt, and identifies existing knowledge gaps. Messages emerging from this review suggest that Sri Lanka's mean temperature during the North-East (December-February) and South-West (May-September) monsoon seasons will increase by about 2.9 ^{0}C and 2.5 ^{0}C, respectively, over the baseline (1961-1990), by the year 2100 with accompanying changes in the quantity and spatial distribution of rainfall. Extreme climate events are expected to increase in frequency. These changes will bring about widespread impacts on the country's agriculture and economy. For example, an increase of 0.5 ^{0}C in temperature can reduce rice yield by approximately 6 %; extended dry spells and excessive cloudiness during the wet season can reduce coconut yield resulting in annual losses between $32 and $73 million to the economy. Pilot studies in the Galle District suggest that sea level rise could inundate about 20 % of the land area of Galle's coastal District Secretariat Divisions. Adaptation measures already undertaken in the agriculture sector include the development of low water consuming rice varieties and the use of micro-irrigation technologies. Tools have been developed for predicting seasonal water availability within the Mahaweli Scheme and annual national coconut production. However, Sri Lanka is yet to undertake a comprehensive national study on the vulnerability of her water resources and agriculture to climate change. The formulation of detailed and reliable future climate scenarios for the country is therefore, urgently required.

Introduction

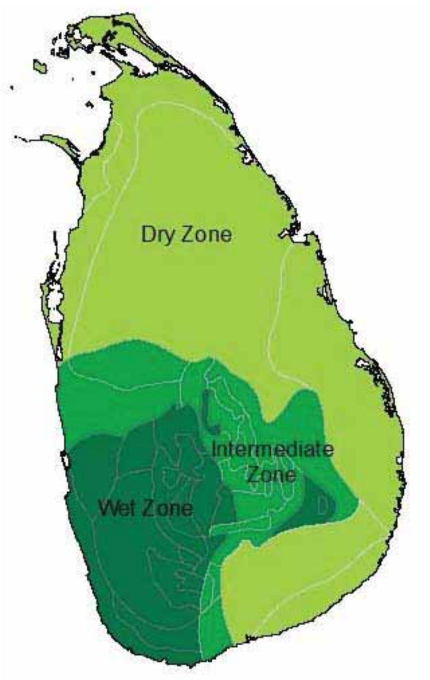
The Intergovernmental Panel on Climate Change (IPCC 2007) defines climate change as "a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer." The IPCC definition refers to changes in climate over time due to both natural variability as well as anthropogenic activities, as opposed to the use of the United Nations Framework Convention on Climate Change (UNFCC), where climate change refers to "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability, observed over comparable time periods." (IPCC 2007). For the purpose of this review the IPCC definition is adopted since generally climate change research and activities that have been carried out in Sri Lanka do not differentiate between natural and human induced variability. However, be it due to natural variability or human activity, a pronounced change in the country's climate is observed, as evidenced by a number of recent studies, which are presented in the section on present climate, observed changes and future projections. Many of these studies were fed into the IPCC's Third and Fourth Assessment Reports. After the IPCC's Fourth Assessment Report (AR4) in 2007, which projected an alarming increase in global average temperature, being in the range 0.3-6.4 ^{0}C, at the end of the twenty-first century (IPCC 2007), researchers have divulged even more disconcerting information on greenhouse gases (GHG) in the atmosphere (the build-up of which is the primary cause of global warming and associated changes in climate). The global carbon dioxide (CO_2) concentration in 2008 was 387 ppm and was the highest on record in human history (NOAA 2009; Adam 2008). The present GHG emissions are 'far higher than even the worst case scenario' envisaged by the AR4 (Irwin 2009). In this context, limiting the rise in global temperature to 2^{0}C above pre-industrial levels (the EU long-term climate goal popularly regarded by many as 'the' climate target to achieve) is unlikely to be realized unless stringent GHG emission reduction targets are agreed and adhered to. Such global changes will surely alter Sri Lanka's climate even further. Sri Lanka, being an island state, is especially vulnerable to all identified impacts of climate change including rise in land and sea surface temperature, changes in precipitation amount and pattern, increase in extreme climate events and rise in sea level. These 'direct' impacts, in turn trigger a wide variety of secondary effects on water resources, agriculture, livelihoods, health and well-being, the economy and nature. It is critically important that these impacts are identified, quantified, and suitable action is initiated to adapt to them. This paper attempts to review the progress already made in this direction, especially with regard to water resources and agriculture, and to identify key knowledge gaps and future research needs.

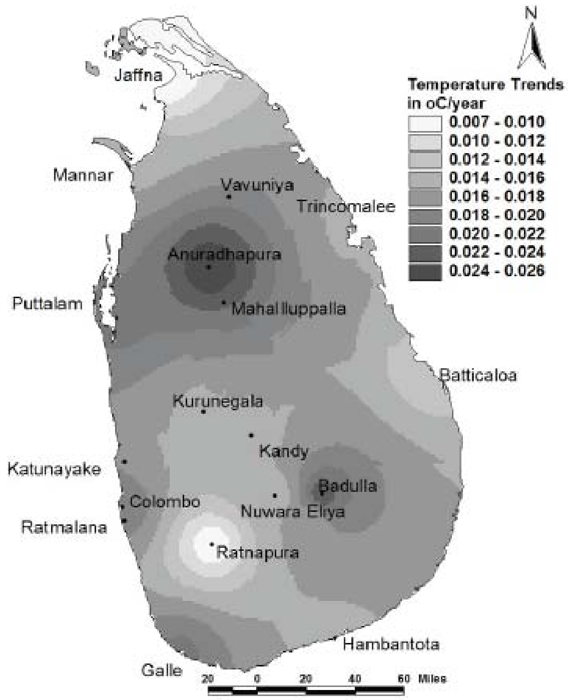
Present Climate, Observed Changes and Future Projections

Present Climate

Sri Lanka is an island in the Indian Ocean situated just north of the equator. Its topography consists of a central highland (altitudes of 300 m amsl) that is surrounded by an extensive lowland area. The long-term mean annual temperature is 27 ^{0}C in the lowlands and 15 ^{0}C in the highlands (Nuwara Eliya at an altitude of 1,895 m amsl; Chandrapala 1996). Mean annual rainfall ranges from under 1,000 mm in the north-western and south-western coastal areas to over 5,000 mm in the western slopes of the central highlands. The spatial pattern of precipitation is strongly influenced by topography and two seasonal wind regimes (Chandrapala 1996). The South-West Monsoon (SWM) is from May to September and the North-East Monsoon (NEM) from December to February. There are two inter-monsoonal periods from March to April (first inter-monsoon – IM1) and from October to November (second inter-monsoon – IM2). Sri Lanka consists mainly of three climatic zones: The Wet Zone, Dry Zone and the Intermediate Zone (Figure 1). The El Nino-Southern Oscillation (ENSO) is a primary mode of climate variability in the South Asian region as a whole (Zubair et al. 2008).

Figure 1. Climatic zones of Sri Lanka (left) and observed warming trends in mean annual temperature (right).





Source: Zubair et al. 2005

Observed Changes in Climate

Time series data of annual mean temperature anomalies from1871-1990 show a significant warming trend throughout the country during the latter half of this period (Chandrapala 1996; Fernando and Chandrapala 1992). The rate of increase in temperature from 1961 to 1990 is 0.016 ^{0}C per year (Chandrapala 1996), which is higher than the global average rate of 0.013 ^{0}C per year for the period 1956 to 2005 (IPCC 2007). Sri Lanka's 100 year warming trend from 1896 to 1996 is 0.003 ^{0}C per year, while it is 0.025 ^{0}C per year for the 10-year period of 1987-1996 (Fernando 1997), indicating faster warming in more recent years. Seasonal mean temperatures for the agricultural seasons yala (April - September) and maha (October – March) also display similar warming (Basnayake et al. 2002). Mean (annual and seasonal) daytime maximum and mean (annual and seasonal) night-time minimum air temperatures have both increased during 1960-2001 with trends of 2.6 ^{0}C/100 years and 1.7 ^{0}C/100 years, respectively (Basnayake et al. 2002; Zubair et al. 2005). The highest warming trends in the country have been observed in Anuradhapura and Badulla (Figure 1; Zubair et al. 2005). Scientists attribute this warming trend, seen throughout the country, to both the enhanced greenhouse effect as well as the 'local heat island effect' caused by rapid urbanization (Basnayake 2008; Basnayake et al. 2003; Fernando and Basnayake 2002; Emmanuel 2001).

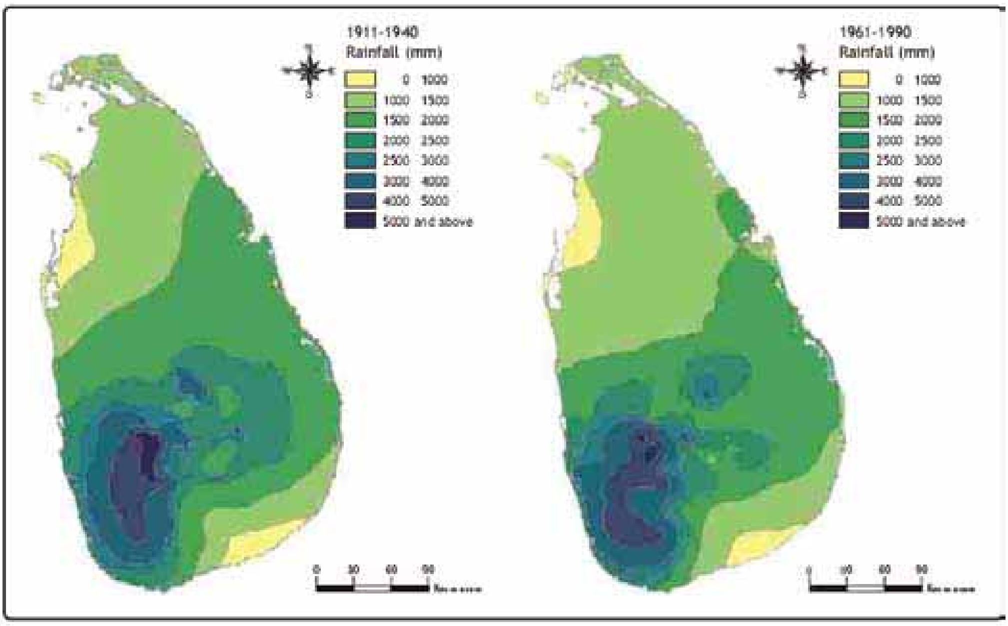
There has not been a significant trend in Sri Lanka's mean annual rainfall (MAR) during the past century, nevertheless, a higher variability is evident (Jayatillake et al. 2005; L. Chandrapala NDMC, pers. comm.). However, more recent data records reveal a decreasing trend: MAR during 1961-1990 has decreased by 144 mm (7 %) compared to that during 1931-1960 (Chandrapala 1996a; Jayatillake et al. 2005); and rainfall data for the period 1949-1980 at 13 stations reveal decreasing trends with steeper downward trends in recent decades. However, there is a wide disparity in the magnitude of changes that have taken place in different rainfall seasons and different spatial locations. Although no significant changes in rainfall amount have been observed in the SWM and the IM2, rainfall in the NEM (the maha season when the majority of agricultural areas in the country receives rainfall) and the IM1 has reduced with the NEM showing increased variability (Jayatillake et al. 2005; Basnayake et al. 2002; L. Chandrapala NDMC, pers. comm.).

A few authors have made observations on rainfall in the central region: for example, an analysis of inter-annual as well as intra-annual rainfall trends of the central region from 1964-1993, suggests that there is a decrease in MAR, with the IM1 showing the highest decrease (Herath and Ratnayake 2004); Shantha and Jayasundara (2005) also observe a 39.12 % decrease in MAR in the Mahaweli upper watershed from 1880 to 1974. Bandara and Wickramagamage (2004) reveal that rainfall on the western slopes of the central highlands has declined significantly from 1900 to 2002 due to reduced SWM rainfall (this region has the highest MAR in the country, often exceeding 5,000 mm). The reduction in observed rainfall in the central region is attributed to the interaction of both local and global factors (Wickramagamage 1998). In the country as a whole, the number of consecutive dry days has increased while the number of consecutive wet days has reduced (Ratnayake and Herath, 2005; Premalal 2009). Recent analysis of the spatial pattern of rainfall also indicates an expansion of the dry zone (MAR<1,750 mm) (Figure 2; Imbulana et al. 2006).

The intensity and frequency of extreme climate events (floods and droughts) have increased in recent times, triggering an increase in natural disasters (Imbulana et al. 2006;

Herath and Ratnayake 2004; L. Chandrapala NDMC, pers. comm.). The country has already experienced 2 years of serious drought and one major flood event within the first 5 years of the twenty-first century (Imbulana et al. 2006) and the districts of Ratnapura and Kalutara, which are generally flooded once or twice a year, experienced floods four times in 2008 including one severe event (L. Chandrapala, NDMC, pers. comm.). According to Ratnayake and Herath (2005), the daily rainfall intensity (amount of rainfall per rainy day) and the average rainfall per event, have both increased, triggering an increase in landslides. Upward trends in the occurrence of thunder activity as well as increased lightening hazards have also been observed (Fernando and Chandrapala 1994; Jayaratne 1997).

Figure 2. A comparison of average rainfall 1911-1940 and 1961-1990 indicating expansion of the dry zone (MAR < 1,750 mm).



Source: Imbulana et al. 2006 (original image prepared by U. R. Ratnayake)

The current rate at which the sea level is rising in the coastal areas of Asia is reported to be 1-3 mm/year, which is marginally greater than the global average (Cruz et al. 2007). Evidence also suggests that there has been an accelerated rate of sea level rise over the past decade (3.1 mm/year) compared to that over the twentieth century as a whole (1.7 to 2.4 mm/year) in Asia (Cruz et al. 2007).

Future Climate Projections

Studies that spell out future climate scenarios for Sri Lanka are scarce and even the ones that exist appear to project contradictory results, especially with respect to future rainfall. However, there is a general consensus within them that Sri Lanka will become increasingly warmer during the twenty-first century, although the projected magnitude of temperature increase differs from study to study. IPCC regional projections based on AR4 Atmospheric Ocean General Circulation Models (AOGCMs or simply - GCMs) suggest a significant acceleration of warming in Asia over that observed in the twentieth century; warming will be stronger than the global mean in South Asia while higher warming is projected during the NEM than during the SWM (Cruz et al. 2007). Temperature increases of 5.44 ^{0}C and 2.93 ^{0}C are projected over South Asia in the summer of 2070-2099 (compared to 1961-1990) for the two IPCC emission scenarios: A1F1 (highest future emissions) and B1 (lowest future emissions - Cruz et al. 2007; IPCC 2002). Other regional climate models for South Asia also project widespread warming in the region, including in Sri Lanka (rise in annual mean temperature in the range 2.5–4 ^{0}C for IPCC scenario A2 and 2–3 ^{0}C for B2), towards the end of the twenty-first century (see Kumar et al. 2006: Islam and Rehman 2004). Both, Kumar et al. 2006 and Islam and Rehman (2004) confirm IPCC's projections of higher warming during the NEM and lower warming during the SWM.

A few studies have attempted to statistically downscale projections of GCMs over Sri Lanka and project mean temperature increments of varying magnitudes by 2100, for example, Basnayake et al. (2004) predicts 2-3 ^{0}C under scenario A1F1, 0.9-1.4 ^{0}C under B1 and 1.7-2.5 ^{0}C under B2; Basnayake (2008) predicts 2.9 ^{0}C in NEM season and 2.5 ^{0}C in SWM season. De Silva (2006b) predicts increases of 1.6 ^{0}C under A2 and 1.2 ^{0}C under B2 by 2050 and that increases will be mainly in the north, north-eastern and north-western regions (all within the dry zone). Meanwhile, Jayatillake and Droogers (2004) suggest a 0.5 ^{0}C increase in 2010-2039 and a 2-3 ^{0}C increase in 2070-2099 within the Walawe Basin in southern Sri Lanka. Zubair et al. (2005) constructed 1 km resolution present climatology fields (i.e., minimum, mean and maximum temperatures, rainfall and solar radiation) and projected future temperature climatology fields for 2025 and 2050 by assuming that present trends (1960-2001) will continue.

Rainfall projections for Sri Lanka within this century appear to be confusing and sometimes contradictory. While the majority of them project higher MAR, a few project lower MAR. Out of those models which project higher MAR, some, such as the AR4 models (Cruz et al. 2007), regional climate models by Kumar et al. (2006) and Islam and Rehman (2004), and statistically downscaled projections from the HadCM3 model by De Silva (2006b), all show increases in MAR under a range of IPCC scenarios (A1F1, B1, A2, B2). De Silva (2006b) further elaborates that these increases will be 14 % for A2 and 5 % for B2 by 2050 with reference to 1961-1990. While statistically downscaled projections from the HadCM3 and CSIRO models by Basnayake et al. (2004) show an increase in MAR, the CGCM model shows a decrease in MAR for scenarios A1F1, A2 and B1. Seasonally, AR4 models (Cruz et al. 2007), De Silva (2006b) and Basnayake and Vithanage (2004a) project an increase in SWM rainfall (the season when rainfall is confined mainly to the wet zone) and a decrease in NEM rainfall (the season when the majority of the dry zone receives rainfall). De Silva (2006b) envisages a 26-34 % decrease in the NEM rainfall and a 16-38 % increase in the SWM rainfall compared to 1961-1990 for scenarios B2-A2; this will result in enhanced rainfall in the wet zone, northern, north-western and south-western dry zones and reduced rainfall in other dry zone areas such as Anuradhapura, Batticaloa and Trincomalee (Figure 1). A 2 % increase in rainfall is projected in the intermediate zone by 2050 (De Silva 2006b).

The two regional climate models (Kumar et al. 2006; and Islam and Rehman, 2004), and downscaled projections by Basnayake and Vithanage (2004b) suggest increases in both SWM and NEM rainfall (for a range of IPCC scenarios from A1 to B2), with Basnayake and

Vithanage (2004b) suggesting higher increases in SWM than in NEM. They also envisage much higher increments of rainfall on the windward side of the central hills in each monsoon season and lesser increments on the leeward side by 2100. In contrast, downscaled CGCM model projections (Basnayake et al. 2004) indicate decreases in both SWM and NEM. A recent study by the Purdue University, especially on the South Asian summer monsoon also projects a weakened and delayed (by 5-15 days by the end of the twenty-first century) SWM over the majority of South Asia. However, image results of future projections suggest increased SWM rainfall in western Sri Lanka (which is generally wetter than the east) and decreased rainfall in the eastern part. This spatial trend has also been noted by De Silva (2006b) and Basnayake and Vithanage (2004b). Meanwhile, Jayatillake and Droogers (2004) project a somewhat wetter situation with simultaneously more variation in annual precipitation in the Walawe Basin. Shantha and Jayasundeara (2005) envisage a 16.6 % reduction in rainfall in the upper Mahaweli watershed by 2025.

The IPCC envisages an increase in the occurrence of extreme weather events including heat-waves and intense precipitation events in South Asia within this century; inter-annual variability of daily precipitation in the SWM is also projected to increase (Cruz et al. 2007). An increase of 10-20 % in tropical cyclone intensities (for a rise in sea surface temperature of 2-4 ^{0}C relative to current threshold temperature), amplification of storm surge heights (due to stronger winds), with increase in sea surface temperatures and low pressures associated with tropical storms could contribute to an enhanced risk of coastal disasters (Cruz et al. 2007).

This review suggests that considerably more work is needed to verify and refine the available climate projections for Sri Lanka. Scientist are of the view that since South Asia, in general, is unique from the rest of the world, with very complex topography, global models like the ones featured in the IPCC reports have difficulty capturing some of the more subtle atmospheric processes. Therefore, understanding the potential impacts of future climate change in this region requires an improved understanding of a host of climate processes. Consequently, it is of utmost importance that projections from detailed high-resolution regional climate models (RCM) are employed to obtain reliable climate scenarios for Sri Lanka. Accurate quantification of impacts and identification of adaptation strategies both depend on it. Climate simulations by the Purdue University, using model RegCM3, which accurately recreate the monsoon season of past years, are believed to be the most detailed to date for the South Asian Region.

Impacts of Climate Change

Impacts on Water Resources

There are 103 distinct radial draining river basins in Sri Lanka with considerable variations in hydrological characteristics. Sixteen (16) of these are classified as wet zone rivers and carry approximately half the annual runoff (Arumugam 1969). One half of all rivers have zero or negligible flow during the yala (dry) season (Amarasinghe et al. 1999). Sri Lanka depends primarily on its surface water resources for agricultural, domestic and industrial uses. Agriculture is largely sustained by direct rainfall and irrigation water extractions from rivers, while 42 % of electricity is generated from hydro sources. However, groundwater use is also rapidly increasing in the country (IWMI 2005). In this context, accurate quantification of climate change impacts on water resources will be the key to successful adaptation, as Sri Lanka transforms gradually from an agriculture-oriented society to a more industrialized one. The country will face the dual challenge of adapting to climate change while meeting rising demands on water resources due to the growing population and increased allocations to sectors other than agriculture. One school of thought is that while Sri Lanka will actually gain in terms of mean annual water availability due to climate change, its increased variability and inequitable spatial distribution (wet areas getting wetter and dry areas getting drier: Basnayake, 2008; Basnayake et al. 2004; Basnayake and Vithanage, 2004b; De Silva, 2006b) will negatively impact agriculture and food security. The brunt of the impact of climate change on water resources is expected to be borne by the north-eastern and eastern dry zone of the country. The changes in rainfall and temperature, together with other climatic factors, would increase the potential maximum annual soil moisture deficit (MASD) significantly in the dry zone, where some of the agriculturally intensive areas are located and the availability and reliability of water resources are already under severe pressure (De Silva 2006b, De Silva et. al. 2007). The areas with the highest MASD (1961-1990) are located in the north and the east, notably in Jaffna, Mannar, Vavuniya, Trincomalee, Anuradhapura and Batticaloa, while Colombo, Galle, Ratnapura and Nuwara Eliya have the lowest (De Silva 2006a). By 2050, Jaffna will experience a 12 % increase (from 1,162 mm to 1,305 mm) in MASD and in general, the northern, eastern and south-eastern areas (covering the whole of the dry and intermediate zones) will see substantial increases in MASD (De Silva 2006b). However, among the dry zone areas, Hambantota, in the southern tip of the island, is expected to see a decrease in MASD, while also gaining in MAR (De Silva 2006a; Jayatillake and Droogers 2004).

As stated earlier, reduction in rainfall in the central highlands have been observed and projected by several authors. Since the central highlands contribute the largest volume of water for hydro-power generation and subsequently for irrigation (through multipurpose reservoirs in the Mahaweli System), negative climatic changes in this region will very likely result in significant negative ecological and economic impacts. The Kotmale, Victoria, Randenigala and Rantembe reservoirs, constructed in the heart of the upper Mahaweli watershed, supply nearly one-third (29.11 %) of the national power generation and 23 % of the irrigation water supplied by major irrigation schemes (Shantha and Jayasundara 2005). Since the Mahaweli is a multi-purpose water supply scheme, hydro-electricity generation by associated power stations is governed by downstream irrigation requirements. In the event of low runoff, water allocation between the two sectors (hydropower and irrigation) will be problematic. This emphasizes even more the need for reliable climate projections for the country so that appropriate adaptation strategies for the two sectors are formulated based on those projections.

Research on climate change impacts on groundwater resources in Sri Lanka, both in terms of quantity and quality, is notably absent, except perhaps in the Walawe Basin (see Ranjan et al. 2007). For example, the country’s dry zone area suffers from excess fluoride (Seneviratne and Gunatilaka 2005), while sea level rise due to climate change is expected to increase salinity in coastal aquifers. A global scale evaluation of fresh groundwater resources has found that groundwater resources in South Asia are highly vulnerable to salt water intrusion due to global warming (Ranjan et al. 2007). Some other unanswered questions are whether Sri Lanka will be able to satisfy its national water needs (agricultural, industrial and domestic) and how its surface water quality will vary in the twenty-first century amid increased warming.

Impacts on Agriculture

The impact of climate change on agriculture may be broadly categorized into three areas: impact of temperature on crop growth; impact of CO_2 on crop growth and impact of precipitation on crop growth. As regards the impact of temperature, there are two possible effects that could arise, and which have been distinguished as physiological effects, at the level of plants and plant organs; and the crop ecosystem effects, at the field or regional level (Jayatillake and Droogers 2004). Efforts have been made to quantify the impact on crop growth due to the combined effects of enhanced atmospheric CO_2 and increased temperatures, both globally as well as within Sri Lanka. According to the results of world-wide experiments, combined and collected by the Centre for the Study of Carbon Dioxide and Global Change, in Tempe, Arizona (www.co2science.org), increases in potential crop growth due to enhanced CO_2 levels (Table 1) are indicated for rice, Sri Lanka's staple food, and other vegetables (Jayatillake and Droogers 2004). Meanwhile other studies show that a 0.1-0.5 ^{0}C increase in temperature can reduce rice yield by approximately 1-6 % (Vidanage and Abeygunawardena 1994). However, more recent experiments carried out in Sri Lanka suggest that rice yields respond positively to elevated CO_2 (increases of 24 % and 39 % in the two seasons) even at higher growing temperatures (>30 ^{0}C) in sub-humid tropical environments (De Costa et al. 2006).

Table 1. Increases of potential crop growth as a result of enhanced CO_2 levels.

Crop	Period	IPCC Scenario A2 (%)	IPCC Scenario B2 (%)
Rice	2010-2030	20	10
	2070-2100	40	20
Beet	2010-2030	10	5
	2070-2100	20	10
Tomato	2010-2030	15	8
	2070-2100	30	15

Source: Jayatillake and Droogers 2004

The real threats to rice cultivation might be the third factor impacting crop growth, namely, changes in precipitation amount and temporal distribution. Nearly 72 % of paddy production is grown during the wet (*maha*) season in dry areas, where water resources are already stressed (De Silva et al. 2007). De Silva et al. (2007) suggest that by 2050, the average paddy irrigation water requirement during the *maha* season will increase by 23 % and 13 %, respectively, in A2 and B2 scenarios due to reductions in average rainfall, increase in potential evapotranspiration and early ending of rainfall. Irrigation water requirements for other field crops cultivated in the dry and intermediate zones during the dry (*yala*) season will also significantly increase (De Silva 2006a). However, positive impacts are shown in the extreme south (De Silva et al. 2007; Jayatilleke and Droogers 2004). According to Jayatilleke and Droogers (2004), rice yields in the Walawe Basin will increase as a result of enhanced CO_2 levels and higher precipitation, although a substantial variation in yield is expected. Overall, the impact on food production will be positive in the Walawe Basin.

Plantation crops, tea, rubber and coconut, are the next most important crops to Sri Lanka's economy, being some of the main foreign exchange earners and generating income for the majority of unskilled laborers in the country. Several studies have been undertaken to assess the impact of climate change on plantation crops. Wijeratne et al. (2007) have found that tea cultivations at low- and mid-elevations are more vulnerable to the adverse impacts of climate change, than those at high elevations. They also found that reduction of monthly rainfall by 100 mm could reduce productivity by 30-80 kg of 'made' tea/ha while an increase in ambient CO_2 concentration from the present level (around 370 ppm) to 600 ppm may increase tea yield by 33-37 % depending on elevation. Yield projections also show that rising temperatures and diminishing rainfall reduce tea yield in many tea growing regions except in the up-country wet zone (Wijeratne et al. 2007).

Coconut is almost exclusively grown as a rain-fed crop in Sri Lanka, hence rainfall and temperature are the important climatic factors influencing coconut yield (Peiris et al. 1995; Mathes et al. 1996). Future yields in coconut production under six different climate scenarios, using integrated crop models suggest that the projected coconut production after 2040 in all climate scenarios, when other external factors are non-limiting, will not be sufficient to cater to local consumption (Peiris et al. 2004). Extended dry spells and excessive cloudiness during the wet season can reduce coconut yield so that annual losses can range between \$32 and \$73 million (Fernando et al. 2007). However, on the other hand, during a high rainfall year, the economy could gain by \$42-\$87 million due to high coconut yields (Fernando et al. 2007). Among the different stakeholders in the coconut industry, the coconut oil industry will be most vulnerable to climate change: increasing air temperatures will increase pest and disease problems in the future and, therefore, increased investment in pest control will be required (Peiris et al. 2004).

Climate change is expected to affect Sri Lanka's forest distribution as well, with increases in tropical very dry forest areas (5 %) and tropical dry forest areas (7 %), and a decrease in tropical wet forest areas (11 %) (Somaratne and Dhanapala 1996). Sea level rise caused by global warming poses another threat to coastal agricultural areas due to inundation and salinity intrusion of coastal wetlands and aquifers. Weerakkody (1996) states that inundation will be in the range 41 km^2 for a rise of 0.3 m and 91.25 km^2 for a rise of 1 m for lowlands along the south-west coast. The Galle District (one of Sri Lanka's 25 administrative districts), situated along the south-west coast is further subdivided into 18 District Secretariat (DS) Divisions. Pilot studies suggest that sea level rise could inundate about 20 % of the land area of Galle's five coastal DS divisions (Wickramarachchi, undated). The damage caused could be of higher magnitude if the combined effects of beach erosion, storm surges and coastal flooding are considered along with inundation due to sea level rise. However, on a positive note, a recent study by the WorldFish Centre, Malaysia, which compared the vulnerability of 132 national economies to potential climate change impacts on fisheries under IPCC scenario B2, finds that Sri Lanka's vulnerability is low in this respect (Allison et al. 2009).

Climate change impacts on agriculture invariably impact the country's economy. Seo et al. (2005) find that nationally, the impact on agriculture (rice, tea, rubber and coconut) will result in economic impacts in the range of a decrease of 11 billion rupees (\$96.4 million, minus 20 %) to an increase of 39 billion rupees (\$342 million: plus 72 %) depending on the climate scenario on which the calculations are based. They confirm that climate change damage could be large in tropical developing countries but is highly dependent on the actual climate scenario.

Mitigation and Adaptation to Climate Change

Climate Change Mitigation

Sri Lanka is a signatory to UNFCC and has ratified the Kyoto Protocol on climate change. Therefore, under its obligation to contribute to efforts to mitigate climate change, Sri Lanka made its Initial National Communication on Climate Change in October 2000. Its Second National Communication is under preparation (C. Panditharatne, Ministry of Environment, pers. comm.). According to Sri Lanka's latest GHG inventory (1994), annual emissions stand at 33,630.22 Gg CO_2, 1,098.38 Gg Methane (CH_4) and 162.8657 Gg of Nitrous Oxide (N_2O) (Ministry of Forestry and Environment 2000). The largest contributors to GHG emissions in Sri Lanka are changes in forest and woody biomass stocks; forest and grassland conversion; and liming and organically amended soils. The largest source of CH_4 is the treatment and handling of waste, while the energy sector also contributes in a small scale through incomplete burning of fossil fuel (Ministry of Forestry and Environment 2000). Biomass (47 %), petroleum (45 %) and hydropower (8 %) are the main primary energy resources used in the country (ADB 2006).

Sri Lanka has initiated a host of activities aimed at reducing its GHG emissions including afforestation, reforestation, and development of sustainable energy and incorporation of emission reduction strategies to the transport sector. Studies have been conducted to assess the carbon sequestration potential of Eucalyptus plantations in the up-country region and in-situ Gliricidia plantations, providing innovative thermal energy to desiccated coconut mills in Sri Lanka (Nissanka and Ariyaratne 2003; Fernando and Jayalath 2003). Efforts have also been made to introduce renewable energy such as small hydropower plants, solar and wind energy (Weerakoon and De Silva 2006; Prasad 2006) and biofuels (Ambawatte and Kumara 2007; Ambawatte et al. 2007) to the energy sector. Some innovative projects aimed at mitigating climate change impacts, have also been implemented including the planting of 73,000 trees to offset carbon emissions generated by the tourism industry as part of a 'carbon clean Sri Lanka' campaign, and the installation of ten trial base stations using solar and wind power by Dialog Telekom, a mobile telecommunications provider (Anderson 2009). A number of non-governmental organizations are also active in the country in implementing community-based projects aimed at reducing GHG emissions to the atmosphere, such as through the Small Grants Program of the Global Environmental Facility (GEF).

Apart from the Initial National Communication, Sri Lanka has also developed a Clean Development Mechanism (CDM) policy and strategy and a few CDM projects in the form of small hydropower are already underway. Introduction of Vehicle Emission Standards and the 'Green Lanka' program are other initiatives taken in this direction. The country is also contemplating the introduction of new strategies into the transport sector (heavily dependent on fossil fuels at present) such as promoting public transport instead of private transport within major cities.

Climate Change Adaptation

Adaptation to climate change is defined as any 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (IPCC 2007). Although there are a number of environmental policies, legal enactments and plans that contain provisions that could contribute to reducing or mitigating the effects of climate change, the subject of climate change has not been directly addressed in them (Ministry of Forestry and Environment 2000). Therefore, the Initial National Communication recommends the incorporation of climate change considerations into existing policies. Munasinghe (2008) proposes the adoption of the 'sustainomics' framework (developed by the World Bank) and its tools to integrate climate change policies into Sri Lanka's development strategy, to help make the transition from the risky, 'business-as-usual' scenario to a safer and more sustainable future. Sustainomics seeks to provide a comprehensive, practical framework for making present and future development efforts more sustainable. Using one of its tools called the 'Action Impact matrix,' he identifies that, vulnerability of Sri Lanka's water resources and agricultural output, will be the key challenge to national food security in the wake of CC. Hence, the island's successful adaptation depends on accurate projections of climate change impacts on its water resources and agriculture, and finding ways to manage and adapt to such projections. Some examples of initiatives already undertaken in this regard are explained in the next paragraph. However, a more comprehensive national study, on river basin or district scale, on vulnerability of Sri Lanka's water resources and agriculture to climate change, is an urgent need for the country.

Understanding the present climate is imperative in projecting future climate conditions and impacts. Hence, a significant number of attempts have been made to understand and quantify the effect of climate parameters such as ENSO and Sea Surface Temperature (SST) on Sri Lanka's present climate (see Zubair et al. 2008; Pathirana et al. 2007; Zubair and Ropelewski 2006; Suppiah 1996). Some, such as Zubair et al. (2008), propose short- and medium-term rainfall predictions based on ENSO and SST. Tools for predicting annual national coconut production (Peiris et al. 2008) and seasonal water availability within the Mahaweli scheme (Zubair 2003) make use of such short- and medium-term rainfall predictions. Studies on crop adaptation are performed mainly by six research institutes in the country conducting research on rice, field crops, horticultural crops, tea, rubber and coconut. The Rice Research and Development Institute (RRDI) is involved in developing technologies and appropriate rice varieties that respond positively to increased air temperature and humidity, increased atmospheric CO_2, moisture stress conditions, increased salinity and submergence (W. M. W. Weerakoon, RRDI, pers.com.; Piyadasa et al. 1993). Short-term (low water consuming) rice varieties, suitable for shorter growing seasons, have already been developed and tested (Harris and Satheeswaran 2005). Other adaptation options recommended for rice (especially in the dry zone) include partial shift of present locations to areas projected to receive more beneficial rainfall and changing planting time to suit altered rainfall onset times (De Silva et. al 2007). Introduction of micro-irrigation technologies (Peiris et al. 2006; Aheeyar et al. 2005), shifting from rice to field crops (Chandrika et al. 2004), crop diversification (Nanthakumaran 2004), and investigating the impact of increased temperatures, humidity and moisture stress on crops (Inpadevy and Mahendran 2003; Weerasinghe et al. 2001, Peiris et al. 1993) are other adaptation strategies under consideration. Adaptation measures proposed in the tea sector are: the use of hardy tea clones resistant to drought, pests and diseases; improvement and implementation of soil conservation measures; proper shade management; and expansion of multi-cropping systems (Wijeratne 1996). Coconut farmers have already adopted moisture conservation methods such as cover crops, organic manure, burying coconut husks and contour drains to minimize the effects of less rainfall. Adaptation strategies focused on two alternative development approaches of sustaining food security versus enhancing environmental quality, have been proposed for rice farmers in the Walawe Basin by Jayatillake and Droogers (2004).

Rainwater harvesting and storage during higher rainfall seasons, especially in the dry and intermediate zones, is a viable solution for utilizing available water resources throughout the year. De Silva (2006b) suggests the provision of a rainwater harvesting system to all households in drought-prone areas, making it a prerequisite to receive drought relief. Renovating the existing tanks in the dry and intermediate zones to store excess rainfall during the SWM season, and devising methods to store and transfer excess rainfall in the wet zone to the dry zone are other available alternatives for water resources adaptation when considering the country as a whole (De Silva 2006b). A greater shift towards alternative energy sources, from hydropower and fossil fuels, is advocated in the energy sector (Shantha and Jayasundera 2005), while the Coast Conservation Department (CCD) is in the process of formulating a Climate Change Action Plan for adapting to sea level rise (B. Wickramarachchi, CCD, Pers. Comm.). However, equally important is creating awareness among different stakeholders on vulnerabilities, impacts and adaptation options.

Research Priorities

First and foremost among research priorities is the need for reliable and detailed climate scenarios for the country, without which no country can even begin to understand what its vulnerabilities are. A comprehensive national study on river basin or district scale on the vulnerability of Sri Lanka's water resources and agriculture sectors to climate change should follow. This study should include not only surface water but also groundwater, covering both water quality as well as water quantity issues. Only if the combined impact on agriculture of increased temperature, increased CO_2 in atmosphere and increased or decreased rainfall is quantified, can a true picture of the benefits or costs of climate change on agriculture, food security and the economy be projected. Appropriate adaptation measures may be implemented based on such a study. Central to any research on climate change is the need for data sharing and cooperation among different stakeholder agencies. The Water Resources Board, which already has the mandate to act as the leading coordinating authority in Sri Lanka's water sector, could play a pivotal role as the central agency facilitating such research, including the maintenance of a data depository.

Conclusion

It is evident that Sri Lanka's climate has already changed. This review suggests that although a few attempts have been made to project Sri Lanka's climate in the twenty-first century, such studies lack consensus and their results and projections are even contradictory. However, many available projections indicate that climate change impacts will be large in the dry zone, especially in the north-east and the east. A decline in rainfall in the dry zone, combined with an increase in temperature, evapotranspiration and soil moisture deficit, will have serious impacts on the country's food production, livelihoods and the economy. A recent study finds Sri Lanka to be one of the 'hot-spots' of food insecurity in the Asia Pacific Region, while another suggests yet further decreases (0-15 %) in agricultural productivity by 2080 (Nellemann et al. 2009). Apart from food insecurity, the predicted adverse impacts on the dry and intermediate zones will worsen the existing economic and social inequities and widen the gap between the developed core (Colombo Metropolitan Region) and less developed areas. Therefore, reliable and detailed climate scenarios and a comprehensive national study on the vulnerability of Sri Lanka's water resources and agriculture to climate change are urgently needed so that timely action is initiated towards adapting to such adverse impacts.

Acknowledgments

This study was funded by the International Water Management Institute (IWMI). The authors gratefully acknowledge the support given by the following officers in the literature and information search: Ms. Dharshanie De Silva, World Bank; Mr. Lalith Chandrapala, National Disaster Mitigation Council (NDMC); Dr. B. V. R. Punyawardane, Department of Agriculture; Ms. Karin Fernando, Centre for Poverty Analysis (CEPA); Ms. Chandanie Panditharatne, Ministry of Environment and Natural Resources; Mr. Sarath Premalal, Department of Meteorology; Mr. N. Wickramaratne, Mahaweli Authority; Mr. Harsha Sooriyarachchi, Water Resources Board; Mr. Bandula Wickramaarachchi, Coast Conservation Department (CCD); Mr. H. M. Jayatillake, Irrigation Department; Mr. Gerard Fernando, National Water Supply and Drainage Board; Mr. K. A. U. S., Imbulana, Ministry of Irrigation; Dr. G. G. A. Godaliyadda, Irrigation Department; Mr. L. Manawadu, University of Colombo; Dr. W. M. W. Weerakoon, Rice Research and Development Institute; Dr. A. W. Jayawardena, Public Works Research Institute, Japan; Staff of Sri Lanka Association for the Advancement of Science (SLASS); Ms. Prasanna Sambandamurthy, IWMI; Ms. Yamuna Udumalagala, IWMI; Ms. Priyanka Dissanayake, IWMI; Ms. Arosha Ranasinghe, IWMI.

References

Adam, D. 2008. 'World Carbon Dioxide Levels Highest for 650,000 Years', says US Report. The Guardian (May 13, 2008).

Aheeyar, M. M. M.; Kumara, S. K.; Samarasinghe, G. G. de L. W. 2005. 'The Application of Micro Irrigation Technologies in the Small Farming Sector in Sri Lanka', HARTI.

Allison, E. H.; Perry, A. L.; Badjeck, M.; Adger, W. M.; Brown, K.; Conway, D.; Halls, A. S.; Pilling, G. M.; Reynolds, J. D.; Andrew, N. L.; Dulvy, N. K. 2009. 'Fish and Fisheries', DOI: 10.1111/j.1467-2979.2008.00310.x

Amarasinghe, U. A.; Mutuwatta, L.; Sakthivadivel, R. 1999. *Water scarcity variations within a country: A case study of Sri Lanka*. IWMI Research Report 32. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Ambawatte, H. C.; Kumara, P. O. A. D. 2007. 'Experimental Investigation of Jatropha Oil Based Bio-diesel in Compression Ignition Engines'. *Proceedings of the 63rd Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section E1.

Ambawatte, H. C.; Palayangoda, L. I.; Pathirathna, O. U. A. 2007. 'Design and Development of a Domestic Lamp for Lighting Using Jatropha/Castor Oils'. Proceedings of the 63rd Annual Session of Sri Lanka Association for the Advancement of Science (SLASS). Section E1.

Anderson, T. 2009. Green Mobile Network for Rural Sri Lanka under Trial. *Science and Development Network (SciDev.Net) News*, March 18, 2009.

Arumugam, S. 1969. Water Resources of Ceylon. Water Resources Board, Colombo.

Asian Development Bank (ADB). 2006. 'Country Synthesis Report on Urban Air Quality Management: Sri Lanka'. Discussion Draft, December, 2006. Asian Development Bank.

Bandara, C. M. M.; Wickremagamage, P. 2004. 'Climatic Change and Its Impact on Upper Watersheds of the Hill Country of Sri Lanka'. *Proceedings of International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region*. Colombo, Sri Lanka.

Basnayake, B. R. S. B. 2008. 'Climate Change: Present and Future Perspective of Sri Lanka'. Available at Meteorological Department of Sri Lanka website: www.meteo.gov.lk/Non_%20Up_Date/pages/ccinsl_1.htm (May 05, 2009).

Basnayake, B. R. S. B.; Vithanage, J. C. 2004a. 'Future Climate Scenarios of Rainfall and Temperature for Sri Lanka', *Proceedings of the 60th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section E1. p 222.

Basnayake, B. R. S. B.; Vithanage, J. C. 2004b. 'Rainfall Change Scenarios for Sri Lanka under the Anticipated Climate Change'. *Proceedings of the International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region*, November 17-19, 2004, Colombo, Sri Lanka.

Basnayake, B. R. S. B.; Fernando, T. K.; Vithanage, J. C. 2002. 'Variation of Air Temperature and Rainfall during Yala and Maha Agricultural Seasons'. *Proceedings of the 58th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section E1. p. 212.

Basnayake, B. R. S. B.; Punyawardena Vithanage, J. C. 2003. 'An Investigation of Ambient Air Temperature Trends at Hambanthota – Angunakolapelassa and Nuwara Eliya – Thalawakele'. *Proceedings of the 59th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*.Section E1. p. 194.

Basnayake, B. R. S. B.; Rathnasiri, J.; Vithanage, J. C. 2004. 'Rainfall and Temperature Scenarios for Sri Lanka under the Anticipated Climate Change'. Paper presented at 2nd AIACC Regional Workshop for Asia and the Pacific, Manila, the Phillipines.

Chandrapala, L. 1996a. 'Calculation of Areal Precipitation of Sri Lanka on District Basis using Voronoi Tessalation Method'. In: *Proceedings of National Symposium on Climate Change,* Central Environmental Authority, Colombo. March 7-8, 1996.

Chandrapala, L. 1996b. 'Long-term Trends of Rainfall and Temperature in Sri Lanka'. In: *Climate Variability and Agriculture*, eds. Y. P. Abrol, S. Gadgil and G. B. Pant. New Delhi, India: Narosa Publishing House. pp.153-162.

Chandrika, R. I.; Jayasinghe, A. P. R.; Mahinda, W. 2004. Evaluation of Alternative Crops for a Water Short Irrigation System: A Case Study of 'Kirindi Oya Irrigation and Settlement Project'. *Proceedings of the 60th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section B. p. 127.

Cruz, R. V.; Harasawa, H.; Lal, M.; Wu, S.; Anokhin, Y.; Punsalmaa, B.; Honda, Y.; Jafari, M.; Li, C.; Huu Ninh, N. 2007. 'Asia, Climate Change 2007: Impacts, Adaptation and Vulnerability'. *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C.E. Hanson. Cambridge, UK. Cambridge University Press. pp. 469-506.

De Costa, W. A. J. M.; Weerakoon, W. M. W.; Herath, H. M. L. K.; Amaratunga, K. S. P.; Abeywardena, R. M. I. 2006. Physiology of Yield Determination of Rice under Elevated Carbon Dioxide at High Temperatures in a Sub-humid Tropical Climate. *Field Crops Research* 96 (2-3): 336-347.

De Silva, C. S. 2006a. 'Impacts of Climate Change on Potential Soil Moisture Defecit and Its Use as a Climate Indicator to Forecast Irrigation Need in Sri Lanka'. In: *Symposium Proceedings of the Water Professionals' Day, 2006*, ed. N. D. K. Dayawansa.

De Silva, C. S. 2006b. 'Impacts of Climate Change on Water Resources in Sri Lanka', Paper presented at the 32nd WEDC International Conference, Colombo, Sri Lanka.

De Silva, C. S.; Weatherhead, E. K.; Knox, W. J.; Rodriguez-Diaz, J. A. 2007. Predicting the Impacts of Climate Change – A Case Study of Paddy Irrigation Water Requirements in Sri Lanka. *Agricultural Water Management* 93 (2007): 19-29.

Emmanuel, R. 2001. 'The Thermal Comfort Effects of Urbanization: Bio-climatic and Land-use Changes in the Colombo Metropolitan Region (CMR)'. *Proceedings of the 57th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section C. p. 113.

Fernando, M. T. N.; Jayalath, K. V. N. N. 2003. 'Shifting from Furnace Oil Dendrothermal Energy in Desiccated Coconut Industry of Sri Lanka: An Ex-ante Environmental Economic Analysis'. Paper presented at the 2003 International Conference on Tropical Forests and Climate Change, Manila, the Phillipines.

Fernando, M. T. N.; Zubair, L.; Peiris, T. S. G.; Ranasinghe, C. S.; Ratnasiri, J. 2007. *Economic value of climate variability impacts on coconut production in Sri Lanka*. Working Paper No. 45. AIACC.

Fernando, T. K. 1997. 'Recent Variations of Rainfall and Air Temperature in Sri Lanka'. *Proceedings of the 53rd Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section E1. p. 318.

Fernando, T. K.; Basnayake, B. R. S. B. 2002. 'A Comparative Study of the Ambient Air Temperature at Anuradhapura and Mahailluppallama'. *Proceedings of the 58th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section E1. p. 213.

Fernando, T. K.; Chandrapala, L. 1992. 'Global Warming and Rainfall Variability – Sri Lankan Situation'. *Proceedings of the 47th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section E1. p. 138.

Fernando, T. K.; Chandrapala, L. 1994. 'Study of Thunder Activity over Some Parts of Sri Lanka'. *Proceedings of the 49th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section E1. pp. 191-192.

Harris, K. D.; Shatheeswaran, T. 2005. 'Performance of Improved Four Test Rice Entries of Short Duration (2.5 months) in the Eastern Region of Sri Lanka'. *Proceedings of the 61st Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).*Section B. p. 21.

Herath, S.; Ratnayake, U. R. 2004. Monitoring Rainfall Trends to Predict Adverse Impacts: A Case Study from Sri Lanka. *Global Environmental Change* 14: 71-79.

Imbulana, K. A. U. S.; Wijesekara, N. T. S.; Neupane, B. R (Eds.) 2006. 'Sri Lanka National Water Development Report'. MAI and MD, UN-WWAP, UNESCO and University of Moratuwa, Sri Lanka.

Inpadevy, S.; Mahendran, S. 2003. The Effects of Soil Moisture Stress on the Leaf Area and Yield of Maize Var', Ruwan at Different Growth Stages. *Proceedings of the 59th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section B. p. 53.

Inter-governmental Panel on Climate Change (IPCC). 2002. 'Emission Scenarios'. A Special Report of IPCC Working Group III, eds. N. Nakicenovic and R. Swart.

Inter-governmental Panel on Climate Change (IPCC). 2007. 'Climate Change 2007: Synthesis Report.'

Irwin, A. 2009. Climate Change 'More Serious' as Emissions Soar. *Science and Development Network'*. Available at: www.scidev.net/en/news/climate-change-more-serious-as-emissions-soar.html (April 30, 2009).

Islam, S. U.; Rehman, N. 2004. Assessment of Future Change in Temperature and Precipitation over Pakistan. (Simulated by PRECIS RCM for A2 Scenario). Available at the Hadley Centre, UK Website: http://precis.metoffice.com/docs/final-results-monthly_siraj.ppt#1 (May 11, 2009).

International Water Management Institute (IWMI). 2005. 'Planning Groundwater Use for Sustainable Rural Development'. Colombo, Sri Lanka: IWMI.

Jayaratne, K. P. S. C. 1997. 'Some Features of Thunderstorm Activity in Sri Lanka'. *Proceedings of the 52nd Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).* Section E1. pp. 264-265.

Jayatillake, H. M.; Droogers, P. 2004. Will there be Sufficient Water under Internal and External Changes? Walawe Basin (Sri Lanka). In: *Climate Change in Contrasting River Basins*, eds. J. C. J. H. Aerts and P. Droogers. UK: CABI.

Jayatillake, H. M.; Chandrapala, L.; Basnayake, B. R. S. B.; Dharmaratne, G. H. P. 2005. 'Water Resources and Climate Change'. *Proceedings of Workshop on Sri Lanka National Water Development Report*, eds. N. T. S. Wijesekera, K. A. U. S. Imbulana and B. Neupane. Paris, France: World Water Assessment Programme (WWAP).

Kumar, K. R.; Sahai, A. K.; Krishna Kumar, K.; Patwardhan, S. K.; Mishra, P. K.; Revadekar, J. V.; Kamala, K.; Pant, G. B. 2006. High-resolution Climate Change Scenarios for India for the 21st Century. *Current Science* 90 (3): 334-345.

Mathes, D. T.; Kularatne, J. D. J. S. 1996. 'Uncertainities in Rainfall and the Impact of the Coconut Industry in Sri Lanka'. Paper presented at the Regional Workshop on Climate Change Vulnerability and Adaptation in Asia and the Pacific, Manila, the Phillipines.

Ministry of Forestry and Environment. 2000. 'Initial National Communication under the United Nations Framework Convention on Climate Change – Sri Lanka', Final Draft.

Munasinghe, M. 2008. Rising Temperatures, Rising Risks. *Finance and Development* 45 (1).

Nanthakumaran, A. 2004. 'Crop Diversification of Paddy Lands under Minor Irrigation Systems in the Dry Zone of Sri Lanka: A Case Study from Vavuniya District. *Proceedings of the 60th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section B. p. 33.

National Oceanic and Atmospheric Administration (NOAA). 2009. 'Greenhouse Gases Continue to Climb despite Economic Slump: Carbon Dioxide, Methane Increased in 2008'. Available at: www.noaanews.noaa.gov/stories2009/20090421_carbon.html (April 30, 2009).

Nellemann, C. ; MacDevette, M. ; Manders, T. ; Eickhout, B.; Svihus, B.; Prins, A. G.; Kaltenborn, B. P. (Eds.) 2009. 'The Environmental Food Crisis – The Environment's Role in Averting Future Food Crises', A UNEP rapid response assessment. United Nations Environment Programme, GRID-Arendal, www.grida.no

Nissanka, S. P.; Ariyaratna, C. H. K. 2003. Estimation of Growth, Volume Accumulation and Carbon Sequestration of Eucalyptus Grandis Plantations in Up-country Region of Sri Lanka'. Paper presented at the 2003 International Conference on Tropical Forests and Climate Change, Manila, the Phillipines.

Pathirana, A.; Herath, S.; Yamada, T.; Swain, D. 2007. Impacts of Absorbing Aerosols on South Asian Rainfall. *Climatic Change* 85 (1-2): 103-118.

Peiris, H. K. W.; Gunasena, C. P.; Navaratne, C. M. 2006. Comparative Study of Three Different Micro Irrigation Systems for Their Suitability for Home Gardens in Mapalana Area in Matara, Sri Lanka.

Peiris, R.; Kariyawasam, G.; Jayawardena, S. D. G. 1993. 'A Promising Heat-tolerant Tomato Variety for High Temperature Areas in Sri Lanka'. *Proceedings of the 48th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section B. p. 134.

Peiris, T. S. G.; Hansen, J. W.; Zubzir, L. 2008. Use of Seasonal Climate Information to Predict Coconut Production in Sri Lanka. *International Journal of Climatology* 28 (1): 103-110.

Peiris, T. S. G.; Thattil, R. O.; Mahindapala, R. 1995. An Analysis of the Effect of Climate and Weather on Coconut (*cocos nucifera*). *Experimental Agriculture* 31: 451-460.

Peiris, T. S. G.; Wijeratne, M.; Ranasinghe, C. S.; Aanadacumaraswamy, A.; Fernando, M. T. N.; Jayakody, A.; Ratnasiri, J. 2004. 'Impact of Climate Change on Coconut and Tea Industry in Sri Lanka'. Paper presented at the 2nd AIACC Regional Workshop for Asia and the Pacific, Manila, the Phillipines.

Piyadasa, C.; Sumanasinghe, V. A.; Abesiriwardhena, D. S. de Z. 1993. 'Varietal Screening of Rice for Tolerance to Salinity at Early Growth Stages'. *Proceedings of the 48th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section B. p. 95.

Prasad, R. 2006. 'Green Power to the Sri Lankan People'. *The Guardian* (December 21, 2006).

Premalal, K. H. M. S. 2009. 'Weather and Climate Trends, Climate Controls and Risks in Sri Lanka'. Presentation made at the Sri Lanka Monsoon Forum, April 2009. Department of Meteorology, Sri Lanka.

Ranjan, P.; Gupta, A. D.; KIazama, S.; Sawamoto, M. 2007. Assessment of Aquifer-Land Use Composite Vulnerability in Walawe River Basin, Sri Lanka. *Asian Journal of Water, Environment and Pollution* 4 (2): 1-10.

Ratnayake, U.; Herath, G. 2005. 'Changes in Water Cycle: Effect on Natural Disasters and Ecosystems'. *Proceedings of Workshop on Sri Lanka National Water Development Report*, eds. N. T. S.Wijesekera, K. A. U. S, Imbulana and B. Neupane. World Water Assessment Programme. Paris, France.

Seneviratne, L. W.; Gunatilaka, M. 2005. 'Surface and Groundwater Quality Monitoring and Assessment – Sri lanka', Transactions of the 19th International Congress on Irrigation and Drainage, Beijing, China.

Seo, S. N.; Mendelsohn, R.; Munasinghe, M. 2005. 'Climate Change and Agriculture in Sri Lanka: A Ricardian Valuation'. *Environment and Development Economics* 10: 581-596.

Shantha, W. W. A.; Jayasundara, J. M. S. B. 2005. 'Study on Changes of Rainfall in the Mahaweli Upper Watershed in Sri Lanka due to Climatic Changes and Develop a Correction Model for Global Warming'. Paper presented at the International Symposium on the Stabilisation of Greenhouse Gas Concentrations. Hadley Centre, Met Office, Exeter, UK.

Somaratne, S.; Dhanapala, A. H. 1996. Potential Impact of Global Climate Change on Forest Distribution in Sri Lanka. *Water, Air and Soil Pollution* 92 (1-2): 129-135.

Suppiah, R. 1996. Spatial and Temporal Variations in the Relationships between the Southern Oscillation Phenomenon and the Rainfall of Sri Lanka. *International Journal of Climatology* 16 (12): 1391-1407.

United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). 2009. Sustainable Agriculture and Food Security in Asia and the Pacific.

Vidanage, S. P.; Abeygunawardane, P. 1994. An Economic Assessment of Global Warming on Agriculture: The Case of Paddy Production in Sri Lanka. *Marga* 13 (1): 33-44.

Weerakkody, U. 1996. 'Impact of Sea Level Rise on Beach Erosion and Inundation of Wetands in the Sout-West Coast of Sri Lanka'. Paper presented at the Regional Workshop on Cimate Change Vulnerability and Adaptation in Asia and the Pacific, Manila, the Phillipines.

Weerakoon, S. B.; De Silva, A. P. K. 2006. 'Wind Pumping Based Water Supply Schemes for Remote Villages in Sri Lanka', 32nd WEDC International Conference, Colombo, Sri Lanka.

Weerasinghe, K. D. N.; Leelamanie, D. A. L.; Pushpitha, N. P. G. 2001. 'Construction of an Adjustable Roof Shelter House and Hydroponics System to Grow Lettuce in Hot Humid Climate in Matara'. *Proceedings of the 57th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS)*. Section B. p. 100.

Wickramagamage, P. 1998. Large-scale Deforestation for Plantation Agriculture in the Hill Country of Sri Lanka and its Impacts. *Hydrological Processes* 12 (13-14): 2015-2028.

Wickramarachchi, B. (Undated). 'Risk Profiling for Sea Level Rise in South-West Coast, Sri Lanka', Coast Conservation Department, Sri Lanka.

Wijeratne, M. A. 1996. Vulnerability of Sri Lanka Tea Production to Global Climate Change. *Water, Air and Soil Pollution* 92 (1-2): 87-94.

Wijeratne, M. A.; Anandacoomaraswamy, A.; Amaratunge, M. K. S. L. D.; Ratnasiri, J.; Basnayake, B. R. S. B.; Kalra, N. 2007. Assessment of Impact of Climate Change on Productivity of Tea (camellia sinensis L.) Plantations in Sri Lanka. *Journal of the National Science Foundation of Sri Lanka* 35 (2): 119-126.

Zubair, L. 2003. El Nino - Southern Oscillation Influences on the Mahaweli Streamflow in Sri Lanka. *International Journal of Climatology* 23 (1): 91-102.

Zubair, L.; Ropelewski, C. F. 2006. The Strengthening Relationship between ENSO and North-East Monsoon Rainfall over Sri Lanka and Southern India. *Journal of Climate* 19 (8): 1567-1575.

Zubair, L.; Siriwardhana, M.; Chandimala, J.; Yahiya, Z. 2008. Predictability of Sri Lankan Rainfall Based on ENSO. *International Journal of Climatology* 28 (1): 91-101.

Zubair, L.; Hansen, J.; Chandimala, J.; Siraj, M. R. A.; Siriwardhana, M.; Ariyaratne, K.; Bandara, I.; Bulathsinghala, H.; Abeyratne, T.; Samuel, T. D. M. A. 2005. 'Current Climate and Climate Change Assessments for Coconut and Tea Plantations in Sri Lanka', IRI, FECT, NRMS and UoP Contribution to AS12 Project Report to be submitted to START, Washington, D.C., USA.

Identifying the Impact of Tidal Level Variation on River Basin Flooding

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Abstract

Different parts of Sri Lanka are regularly subjected to a wide range of natural disasters, of which floods are most common. When severe, flooding can decrease the economic and social development of the country and the Government of Sri Lanka has to spend huge amounts of money each year to address such problems. Floods occur mostly because of heavy rainfall combined with human-induced factors in the catchment areas. In this project, tidal level variation is considered as a factor for floods in the river basins. The tidal level changes periodically due to the gravitational attraction from the sun and the moon and the centrifugal force of the earth's rotation. This project studied the relationship between changes in tide and river water level in the mouth of the Kelani River. Tidal data was collected from the Colombo Harbor, and water level data and river flow data was obtained from the Nagalagam Street gauge and Hanwella gauge. It was found that there is a direct relationship between tidal level and flood level in the river mouth area. Therefore, it is proposed that tidal level variations be considered in order to make accurate flood predictions in the river mouth areas.

Introduction

Flood is defined as a body of water that rises and overflows into land settlements that are not normally under water (Kulathilaka 2007). It is known that with the population increases since national independence, land areas have become scarce and as a result, low-income families have occupied the flood plains of rivers, which have been demarcated as reservations. Putting up structures and using land without considering flood risks has often invited flood situations (NDRSC 2008).

Due to the heavy rain resulting from the South-West Monsoon, some districts of the Western, Southern and Sabaragamuwa Provinces of Sri Lanka experience frequent flood situations. The most affected districts are Colombo, Gampaha, Kalutara, Rathnapura, Kegalle, Galle and Matara. Riverine floods develop slowly when there is rainfall for a continuous period or may come in the form of flash floods caused by excessive and intense rainfall over a short duration (Kulathilaka 2007). This usually happens when a tropical cyclone or a depression strikes. The flood effect can be in the form of a local impact in the neighborhood or community or it can affect a very large area.

Floods cause huge damage to physical infrastructure, disrupt economic and social activities, and cause loss of life, and human suffering. In 2007, some 438,880 people were affected by floods and 20 deaths were reported by district authorities due to floods in Sri Lanka (Table 1; NDRSC 2008).

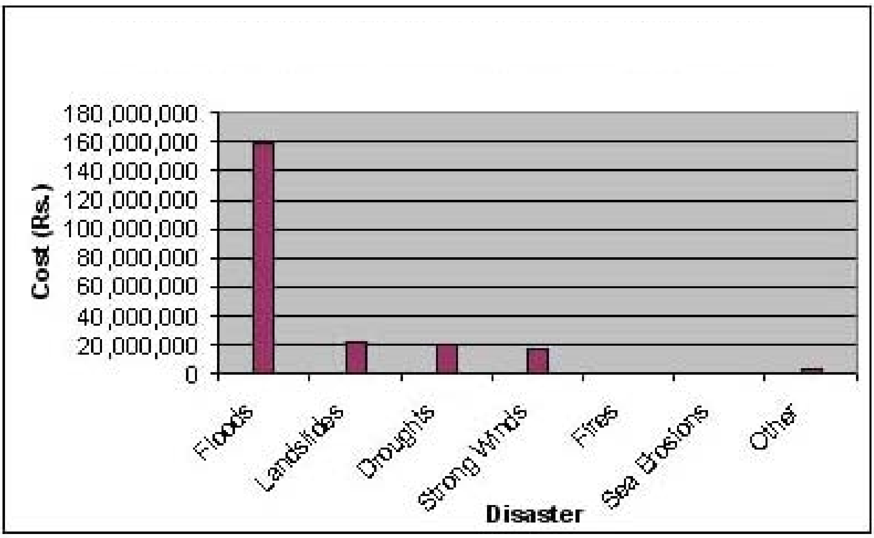
Table 1. Disasters compared in terms of the events of 2007.

Event	Number of affected people	Deaths	Injured	Houses damaged	
				Fully	Partially
Flood	438,880	20	17	2,568	7,237
Land Slide	15,199	14	11	437	1,371
Drought	57,435	-	-	-	-
Strong Wind	4,914	3	51		1,532
Fire	1,193	4	24	282	6
Lightning	9	7	2	-	-
Total	517,630	48	105	3,287	10,146

Source: NDRSC, 2008

According to these figures, floods are the biggest natural disaster related problem in Sri Lanka and the Government of Sri Lanka spent Rs.160 million on relief, rehabilitation and reconstruction programs in 2007 for flood affected districts (Figure 1).

Figure 1. Costs of relief, rehabilitation and reconstruction of Sri Lanka in 2007.



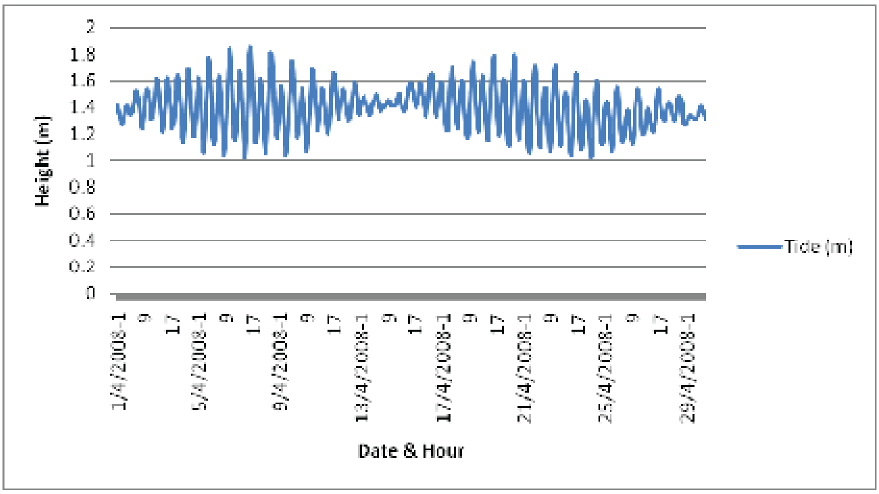
Source: NDRSC 2008

Tides

The surface of all ocean waters rise and fall periodically as a result of the gravitational attraction of the moon and the sun on the earth and the centrifugal force of the earth's rotation (Abbott and Ingham 1992). Far out at sea, tidal changes go unnoticed, but along the shores and beaches, the tides govern many of our water-related activities, both commercial and recreational but are also recognized as a hazard by ship navigators (NOAA 2009).

With the relative movements of the moon and the sun with respect to the earth's location, the tidal level varies. At the same time, the tidal level of a particular locality is affected by the bathymetry of the sea floor, resonance of the basin, friction of the bottom, currents, freshwater inflow and seasonal variations (UTM 2007). Therefore, tides must be observed in the relevant location for accurate applications. Figure 2 shows the tidal variations in the Colombo Harbor in the month of April 2008.

Figure 2. Tidal height changes in April 2008 at the Colombo Harbor tide gauge.



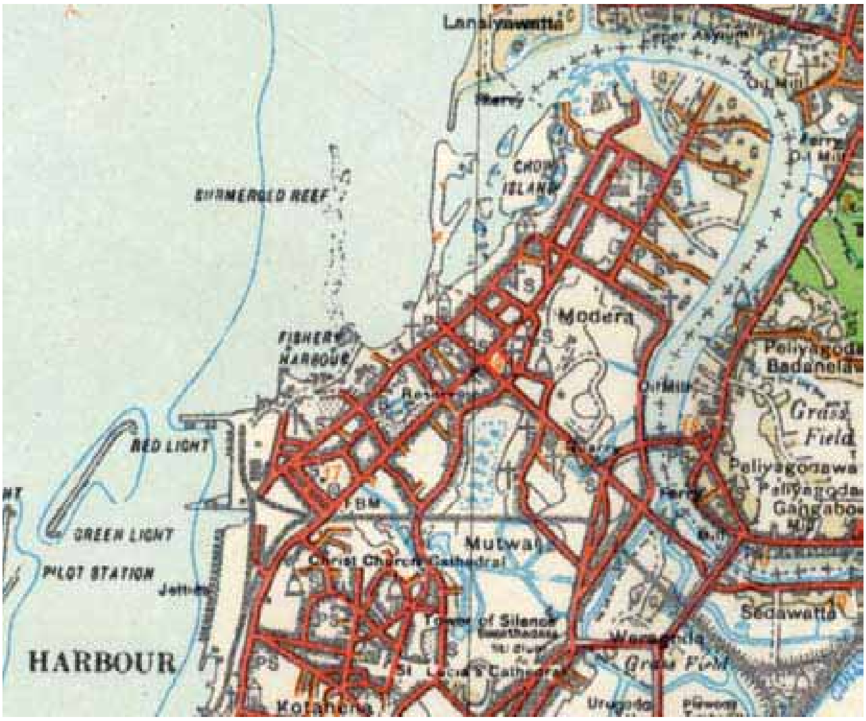
Aim

River flooding is a natural phenomena based on many different factors. This project expected to identify a relationship between tide level changes and river basin flooding near river-mouth areas. It raises the question as to how river flood risk will change under the influence of tidal level variations.

Methodology

Both sides of the Kelani River from Hanwella towards the sea are identified as flood-prone areas. Therefore, this area was selected for the study and data on the river water level and the tidal level at the river mouth were needed. Since there was no tide gauge located at the mouth of the Kelani River, the tide data was obtained from the Colombo Harbor tide gauge, which is situated close to the site (Figure 3). It is maintained by the National Aquatic Resources Research and Development Agency (NARA) and the data was obtained with the help of the National Hydrographic Office (NHO).

Figure 3. Tide gauge and the river water level gauge locations (1 inch sheet - Colombo).



Excessive rain into the upper catchment brings lots of water into the river and increases the river flow. This is the main cause for river flooding. This can be detected with the rising of the water level gauge at the river. For this study, two water level gauges in the Kelani River were used; one at Nagalagam Street and the other one at Hanwella. They are maintained by the Irrigation Department of Sri Lanka. The Nagalagam Street gauge is situated closer to the river mouth (Figure 3) and was compared with the tidal data to identify a pattern. The Hanwella gauge is situated quite far from the river mouth and is used as a measure of river flow and indicator of flooding.

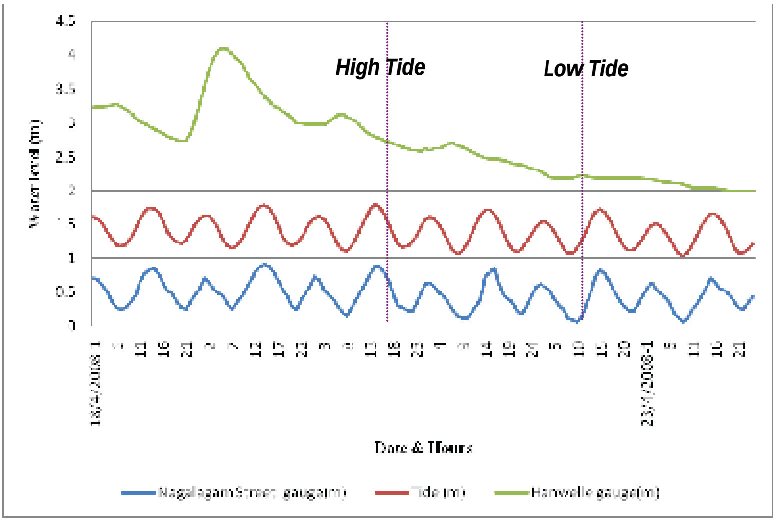
In this study, both tidal and water level data were obtained on an hourly basis on each day from April to June 2008 and analyzed for a pattern to identify a relationship between them. During this period, several flood occasions were reported at the site. From the data obtained, a graphical analysis was carried out for the following cases:

- The water level pattern of the river-mouth with the tidal pattern during the non-flood periods (with low river flow).
- The water level pattern of the river-mouth with the tidal pattern during the flood periods (with high river flow).

Results and Analysis

The water level of the Nagalagam Street gauge changed directly with the Colombo Harbor tide gauge (Figure 4). When there was high tide, the water level at Nagalagam Street was also high; when it was low tide, the water level was also low. In the mean time, the Hanwella gauge shows minimum correlation with the tide gauge (during low water levels and non-flood) because it is situated away from the river-mouth towards the upstream. It gives information about how the water flows in the up-stream-river during the period.

Figure 4. Variation of the tide and river water level during a non-flood period.



From 01:00 hours on 19/07/2008 to 02:00 hours on 21/07/2008, and 11:00 hours on 23/07/2008 to 14:00 hours on 24/07/2008, the water level of the Hanwella gauge rose, and these two periods were identified as flood periods in the Kelani River (Figure 5). During the same period, the water level of Nagalagam Street also increased, but this increment is not as obvious as in the Hanwella gauge. Here, the water level of Nagalagam Street has not behaved in a manner that corresponds with the tides as clearly as during the non-flood periods as shown above. Therefore, the graphs for these durations are magnified and analyzed as follows (Figure 6).

Figure 5. Variation of the tide and river water level during the flood period.

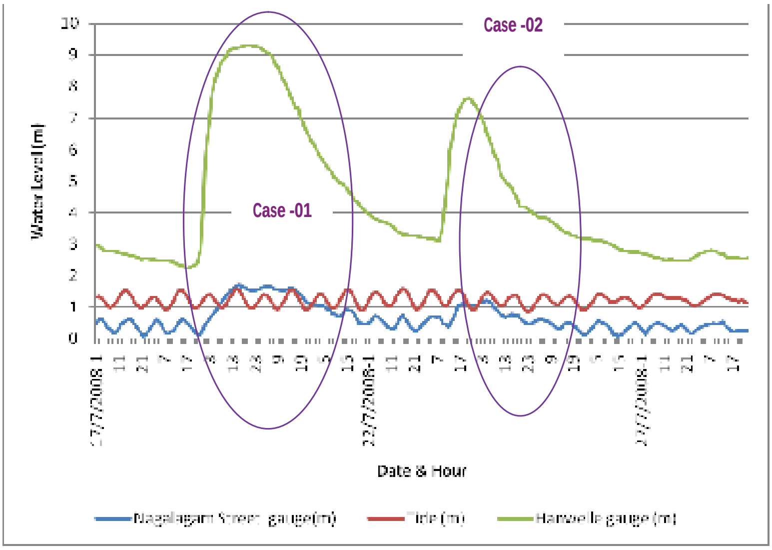
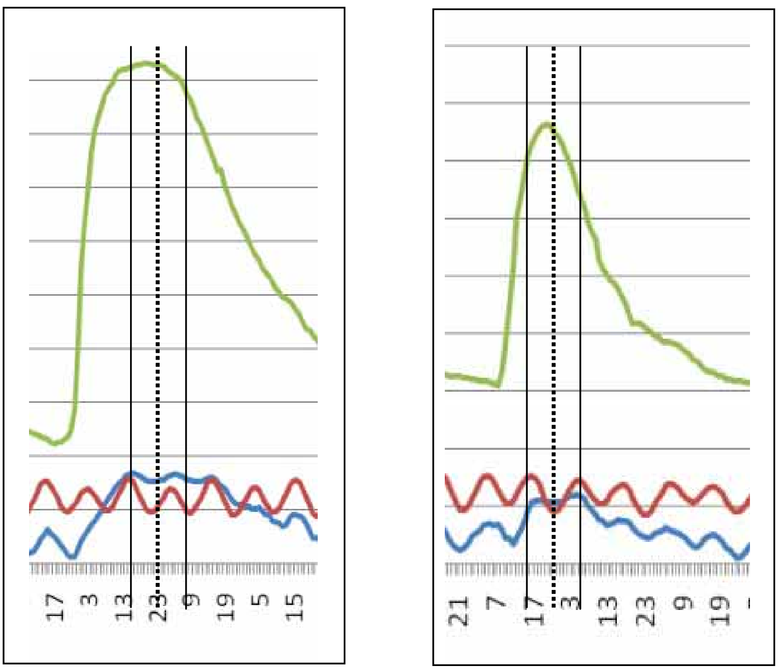


Figure 6. Comparison of the river water level and the tidal level during the flood period.



(a) Case-01 (19-20/07/2008) (b) Case-2 (23-24/07/2008)

At about 13:00 hours (19/07/2008) the tide gauge read a high tide (Figure 6a). At the same time the river water level at Hanwella was getting close to a high level. With this situation, the Nagalagam Street gauge had the highest reading. When it reached 22:00 hours the river water level at Hanwella was at its peak but the Nagalagam Street gauge read a lower water level than at 13:00 hours because the tide level was lower than that at 13:00 hours (low tide). Again the Nagalagam Street gauge reading rose at about 05:00 h the next day, even though the Hanwella gauge was less than at 22:00 h, because it was another high tide time.

The same pattern can be observed in the second case (Figure 6b). At 17:00 hours on 23/07/2008 and 05:00 hours on 24/07/2008, Nagalagam Street gauge read a high water reading because at the same time the tide gauge was giving a high tide and the Hanwella gauge read a high reading. Even though the Hanwella gauge gave the highest reading at 23:00 hours on 22/07/2008, the Nagalagam Street gauge reading was lower than that of 17:00 hours and 05:00 hours, since it was low tide.

Conclusion

The water level of the river-mouth is directly correlated with the tidal variation of the sea. The collective result of the river flow and the tidal level will determine the water level of the lower river areas. When there is high water flow and a high tide, the water level of the river-mouth area is increasing. If the river flow is in a flood risk situation, then the high tide will cause the water level of the river-mouth to increase and it will increase flood risk. With the start of the low tide, the flood risk will decrease. Therefore, when predicting floods in lower river basins, one has to consider the tidal factor, especially in areas where there is a large tidal variation.

Recommendation

The tide gauge that was being used for this work was not situated at the river mouth, therefore, in future studies it is recommended to have a tide gauge at the river mouth.

In this study, we could not collect the river flow data at the river mouth area (Nagalagam Street) along with the water level data, therefore, we used the Hanwella gauge water level data to get an idea about the river flow, but for more accurate work, one has to use the river flow data along with the water level data at the same place.

Usually at river mouths, sand bars are formed due to the tidal currents and other water movements. These will block the natural flow of the fresh water of the river to the sea. Therefore, it is recommended to carryout a bathymetric profile survey at the river-mouth to verify any sand movements during the time.

Acknowledgements

We must express our sincere thanks to Ms. P. P. G. Dais, Deputy Director-Hydrology of the Irrigation Department of Sri Lanka and her staff for providing the water level data and to Mr. R. K. A. Ariyrathne, Surveyor of the National Hydrographic Office NARA for providing the tidal data to carryout this work. Without their valuable contribution, this project could not have been a success.

References

Abbott V. J.; Ingham, A. E. 1992. 'Hydrography for the Surveyor and Engineer', 3rd Edition. Oxford, UK: WileyBackwell.

Atlantic Kayak Tours Experts Center. 2008. 'Navigation Skills: Tides and Currents', Atlantic Kayak Tours Inc.

Kulatilaka, P. H. K. 2007. 'Flood and Obsolete Warning System', *Sunday Observer* (September 29, 2007).

National Disaster Relief Services Center. 2008. Online: www.ndmc.gov.lk . Accessed 15-11-2008.

National Oceanic and Atmospheric Administration, USA (NOAA). Tide and Currents. Online: http://co-ops.nos.noaa.gov/restles4.html. Accessed: January 25, 2009.

Part, C. C. 2001. 'The Environment: Principles and Applications', 2nd Edition. Routledge.

Sverdrup, K. A.; Duxbury, A. C.; Duxbury, A. B. 2002. 'An Introduction to the World's Ocean', 7th Edition. McGraw-Hill College.

UTM. 2007. 'Lecture Notes on Tides', Department of Geomatics, Faculty of Geoinformation Sciences and Engineering, University of Technology, Malaysia.

Rainfall Fluctuation and Changing Patterns of Agriculture Practices

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Abstract

Rainfall fluctuations and the resulting changes in agricultural practices are investigated in this study. The basis for the study is total rainfall and number of rainy days for the period 1961-2002 for 22 meteorological stations scattered throughout the country and the changing pattern of agricultural practices in the crop calendars of 15 reservoirs under the Mahaweli Authority from 1983-2008. From the regression analysis carried out for the 22 rainfall stations, the study recorded declining trends of rainfall in all the wet and intermediated zone stations that were considered, while only Jaffna, Pothuvil and Mulathivue recorded increasing trends. In terms of the number of rainy days, only the Nuwara Eliya station recorded an increasing trend, while all the other stations recorded declining trends. The spatial analysis indicates that the annual total rainfall, which is below 1,600 mm, tends to expand towards the central and south western part of the country. By inspecting the 'Crop Calendar' it was found that both *yala* and *maha* seasons start later, especially in the yala season. Also, in the irrigation schemes, the quantity of water issued and the number of days that it is issued for have declined over the years for both seasons.

Introduction

Rainfall is one of the influencing factors for human activities not only in agriculture-based regions, but also in industrialized urban areas. The rainfall received in any region can vary with physical factors as well as human interactions. The physical factors that can cause such variation could include micro-climatic phenomenon or global changes such as ozone depletion and global warming. Recent observations indicate that there are significant changes in rainfall patterns in both the dry and wet zones in Sri Lanka. Since average rainfall is highly influenced by the extreme cases of rainfall it is very difficult to identify the significant changes of average rainfall but it appears that average rainfall remains unchanged.

Rainfall fluctuations directly affect agricultural activities in any region. According to Prof. Thambyahpillay, "agriculture in the Indian areas is a gamble in the monsoon"; time and again, the monsoon has 'failed' either to appear on time or to produce the rainfall amount that is expected of it. Sri Lanka's main subsistence agriculture is paddy cultivation. Paddy cultivation is highly susceptible to variations in temperature, rainfall, soil moisture, and increases in the intensity and frequency of extreme events. Paddy cultivation is most liable to be affected by large-scale aspects of droughts and floods. The main environmental character that sets paddy apart from other crops is its high water requirement. The island's rainfall trend basically controls the paddy production.

During the past few decades, paddy production has been destroyed either by severe rainfall or the lack of timely rain; and variable rainfalls over the past two decades have pushed farmers to hold back paddy cultivation until the rains arrive. According to Dr. B. Poonyawardena, head of the Agro-climatology Division; the maha growing season usually starts in October and paddy is harvested in March but farmers now wait for the rains to arrive before starting cultivation. The *maha* crop is generally harvested in February, which is traditionally a dry month, but it is now harvested in mid-March.

There have been a number of changes in the harvesting practices due to changing patters of rainfall over the years. According to Mr. Nalin Munasinghe, Programme Associate at the Food and Agricultural Organization (FAO) in Colombo, the planting delays in October may be an indication that the farmers have already begun adjusting to the variation in the rainfall. The farmers may not have scientific knowledge, but they feel the practical need to change. This study attempted to examine the changing pattern of agricultural practices, as indicated by the 'Crop Calendar', in response to rainfall changes. The study especially strived to examine shifts in the cultivated seasons of *yala* and *maha*.

Objectives

The goal of this study is to examine the variations in the rainfall pattern in the country and to observe the impact of rainfall variations on the cultivation patterns for paddy. To examine the variation in the rainfall, only rainfall data was examined, including the monthly total rainfall and the monthly number of rainy days. To observe the changes in the cultivation pattern, the crop calendars of 15 catchments under the Mahaweli Authority were selected. This study attempts to examine the changes in rainfall patterns from different viewpoints using daily rainfall data collected at the 22 main meteorological stations of the Department of Meteorology. This paper identifies spatial and temporal trends in the rainfall received during the period from 1961 to 2002. The objectives of this paper are to:

- Examine the variations in rainfall for the periods 1961-2002, including - variations in the annual total rainfall, variations in the number of rainy days and spatial changes in the rainfall
- Investigate the variations in the 'Crop Calendar' - shifts in the start of *yala* and *maha* seasons and the harvesting dates, variations in water releases, and trends in the number of days of water release

Methodology

Data Sources

This study is entirely based on secondary data obtained from the Meteorology Department and the Mahaweli Authority. The monthly total rainfall and monthly number of rainy days data were obtained from the Meteorology Department for the period 1961–2002 for 22 meteorological stations scattered around the country (Table 1). The crop calendars were obtained from the Water Secretariat of the Mahaweli Authority from 1983–2008 for 15 main reservoirs. The crop calendars record the date of the beginning and end of water issue, which was considered to be the beginning and end of *yala* and *maha*. They also record the amount of water issued and the area under harvest.

Table 1. Data basis for study and research sources.

Variables	Source	Period	Description
Monthly total rainfall	Meteorology Department	1961-2002	Rainfall average for 22 meteorological stations in the country
Monthly number of rainy days	Meteorology Department	1961-2002	Monthly number of rainy days for the 22 meteorological stations
Crop Calendar	Water Management Secretariat; Mahaweli Authority of Sri Lanka	1983-2008	The crop calendars of 15 reservoirs under the Mahaweli Authority from 1983-2008

Data Analysis

Statistical as well as spatial analyses were carried out in this study using Microsoft Excel and Arcview GIS, respectively. In statistical analysis, time series analysis and regression analysis were carried out for monthly total rainfall and the total number of rainy days, and crop data. The total rainfall data was then exported to the Arcview GIS, and the Spatial Interpolation method was used to determine the spatial pattern of the total rainfall from 1961-2002.

Variations in the Annual Total Rainfall

Table 2 represents a summary of the regression analysis carried out for the 22 meteorological stations for the period of 1961 – 2002.

Table 2. Trends in total annual rainfall.

	Station	Slope	Intercept	R^2
	Wet Zone			
1	Colombo	-13.85	29,833	0.133
2	Katunayake	-12.69	27,334	0.124
3	Galle	-10.86	23,853	0.107
4	Ratmalana	-8.9111	20,128	0.072
5	Kandy	-2.784	7,553	0.02
6	Nuwara Eliya	-0.632	3,156	0.00
7	Ratnapura	-0.415	4,555	0.00
	Intermediate Zone			
8	Kurunegala	-7.361	16,637	0.06
9	Diyatalawa	-7.28	15,916	0.049
10	Badulla	-6.117	13,847	0.06

(continued)

Table 2. Trends in total annual rainfall. *(continued)*

	Station	Slope	Intercept	R^2
	Dry Zone			
11	Kankasanturai	-13.64	28,160	0.066
12	Vavuniya	-9.291	19,775	0.082
13	Trincomalee	-7.06	15,530	0.041
14	Hambantota	-6.874	14,645	0.111
15	Batticaloa	-5.077	11,695	0.015
16	Anuradhapura	-4.662	10,464	0.038
17	Mannar	-3.062	6,993	0.022
18	Puttalam	-2.256	5,654	0.009
19	Mahailluppallama	-2.035	5,412	0.006
20	Jaffna	0.732	-2.564	0.00
21	Mullaitivu	7.215	-13,130	0.012
22	Potuvil	28.62	-55,871	0.219

Note: Data have been arranged in descending order according to climatic zone

According to Table 2 it is evident that all stations, except three in the dry zone, show a decreasing trend in the total rainfall. The decreasing trend is especially manifest in the wet zone, where dramatic negative trends are recorded in the four stations of Colombo, Katunayaka, Galle and Ratmalana. In the dry zone all stations, except Jaffna (Figure 1), Mullaitivu and Potuvil, show negative trends. It is remarkable how these three stations show a positive trend, however Mullaitivu and Potuvil only have data records for 15 years due to the civil unrest in the country and, therefore, the projections for those stations cannot be deemed to be accurate. All the other stations in the dry zone record decreasing trends in total rainfall, with Kankasanturai and Vavuniya recording the highest decrease of -13.64 and -9.291 (Table 2). Hambantota, which is situated in one of the driest regions of the country, records a decrease of -6.874 in total rainfall for the period but the rainfall data for the past 5 years shows a slight increase. Anuradapura, Mahailluppallama record decreasing trends of -4.662 and -2.035, and the Mahailluppallama station (Figure 2) has the lowest decreasing trend from the dry zone.

Figure 1. Annual total rainfall of Jaffna.

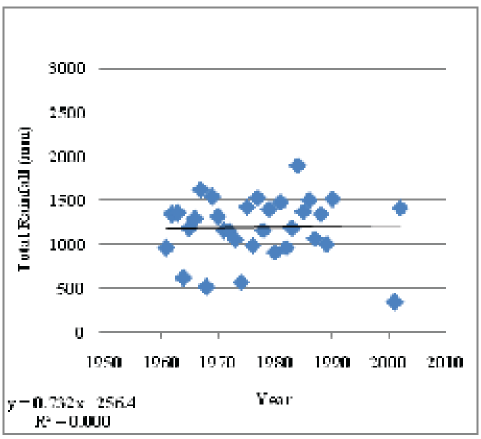
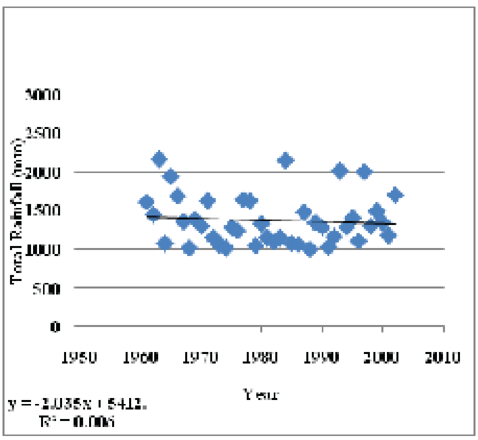


Figure 2. Annual total rainfall of Mahailluppallama.



In Kurunegala, the total rainfall has declined by -7.361 slopes, but by looking at Figure 3, extreme cases of high rainfalls are also evident during this period. The greatest decline in rainfall, of -13.85, in the 22 stations analyzed was recorded in Colombo (Figure 4). Colombo, Galle, Ratmalana and Katunayake are situated in the western windward slope of the central highlands and Nuwara Eliya and Ratnapura are situated in the eastern windward side of the central highlands, which recorded the highest rainfall in the country. The stations on the western windward slope record mediocre declining trends, with Nuwara Eliya recording a decline of -0.632, while Ratnapura on the eastern windward side recorded -0.415 decline trend.

Figure 3. Annual total rainfall of Kurunegala.

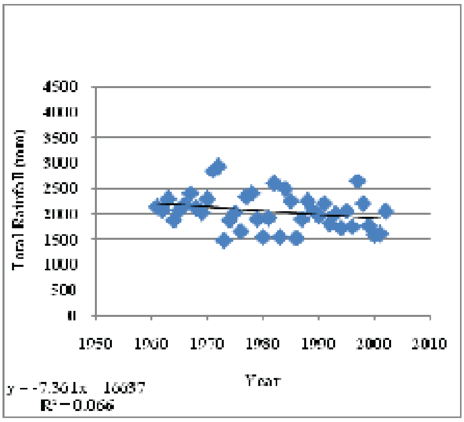
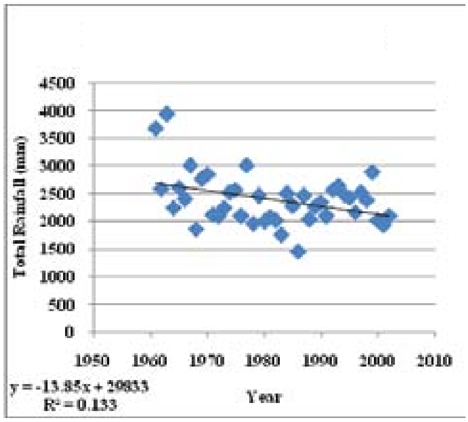


Figure 4. Annual total rainfall of Colombo.



Variations in the Number of Rainy Days

The number of recorded rainy days per month is taken into analysis; the annual total number of days is calculated by adding the total number of days in a year.

The number of rainy days has decreased in all stations except in Nuwara Eliya (Table 3), for which the regression parameter records an increase of 0.047, which is only a slight increase as can be noted from Figure 5. The number of rainy days per year in Nuwara Eliya has not exceeded 250 days but has not dropped below 150 days since the 1980s.

Table 3. Trends in number of rainy days.

	Station	Slope	Intercept	R^2
	Wet Zone			
1	Nuwara Eliya	0.047	107	0.001
2	Kandy	-0.065	312.7	0.002
3	Ratnapura	-0.302	833.2	0.073
4	Ratmalana	-0.376	926.9	1.04
5	Galle	-0.4	991.9	0.098
6	Colombo	-0.537	1,238	0.179
	Intermediate Zone			
7	Badulla	-0.3	753.3	0.048
8	Diyatalawa	-0.13	420.5	0.006

(continued)

Table 3. Trends in number of rainy days. *(continued)*

	Station	Slope	Intercept	R^2
9	Kurunegala	-0.706	1,566	0.27
	Dry Zone			
10	Jaffna	-0.058	193.8	0.001
11	Mahailluppallama	-0.28	675.8	0.066
12	Trincomalee	-0.321	738.2	0.061
13	Mannar	-0.347	757	0.106
14	Batticaloa	-0.355	810	0.074
15	Puttalam	-0.425	946.8	0.095
16	Hambantota	-0.433	970.2	0.099
17	Anuradhapura	-0.458	1,015	0.117
18	Kankasanturai	-0.487	1,040	0.66
19	Vavuniya	-0.488	1,072	0.13
20	Mullaitivu	-0.818	1,714	0.034
21	Potuvil	-0.971	2,013	0.064

Note: Data have been arranged in ascending order according to climatic zone

All the other stations in the wet, intermediate, and dry zones show a declining trend throughout this period (Table 3). The greatest decline in rainy days in the wet zone is recorded in Colombo (regression trend -0.537). The number of rainy days dropped below 200 in the early 1960s and more recently even greater variation is seen (Figure 6). Other wet zone stations such as Galle, Ratmalana, Ratnapura and Kandy also recorded declines in the total number of rainy days in the regression equation. This is of importance as these stations are situated on the windward side of the central highlands, which records a high rainfall during the South West Monsoon period. In the intermediate zone, the number of rainy days has decreased in all three stations, namely Badulla (Figure 7), Diyatalawa and Kurunegala. Kurunegala records a moderate decline in the number of rainy days (regression trend -0.706).

Figure 5. Total number of rainy days in Nuwara Eliya.

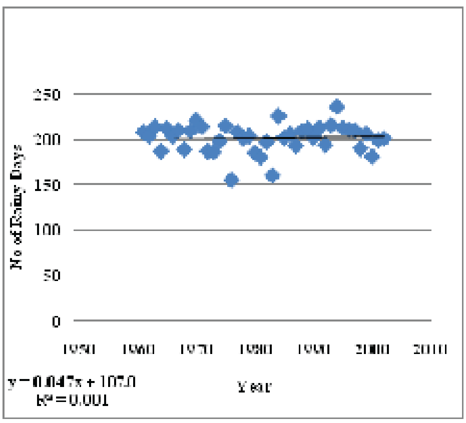
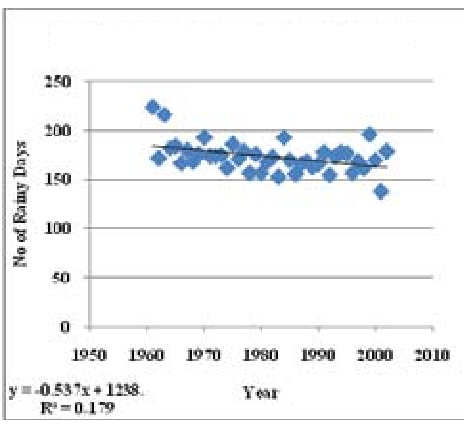


Figure 6. Total number of rainy days in Colombo.



In the dry zone, the highest decline is recorded in Potuvil at -0.971, followed by Mullaitivu and Vavuniya. The lowest decline is recorded in Jaffna, Mahailluppallama and Trincomalee as -0.058, -0.28 and -0.321, respectively. Figure 8 demonstrates the decrease in the number of rainy days in Mahailluppallama. Hambantota, situated in the south of the island, records a moderate decline of -0.433 in number of rainy days. In both Mahailluppallama and Puttalam, there has been a steady decline apart from few deviations between certain years. In both stations, the number of rainy days has not exceeded 150 days since the 1960s.

Figure 7. Total number of rainy days in Badulla.

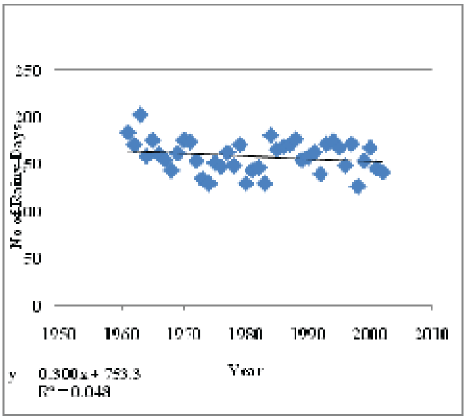
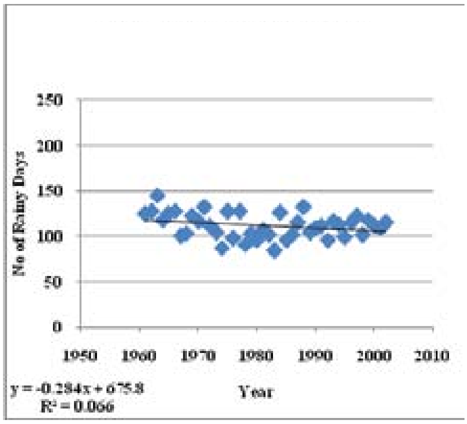


Figure 8. Total number of rainy days in Mahailluppallama.

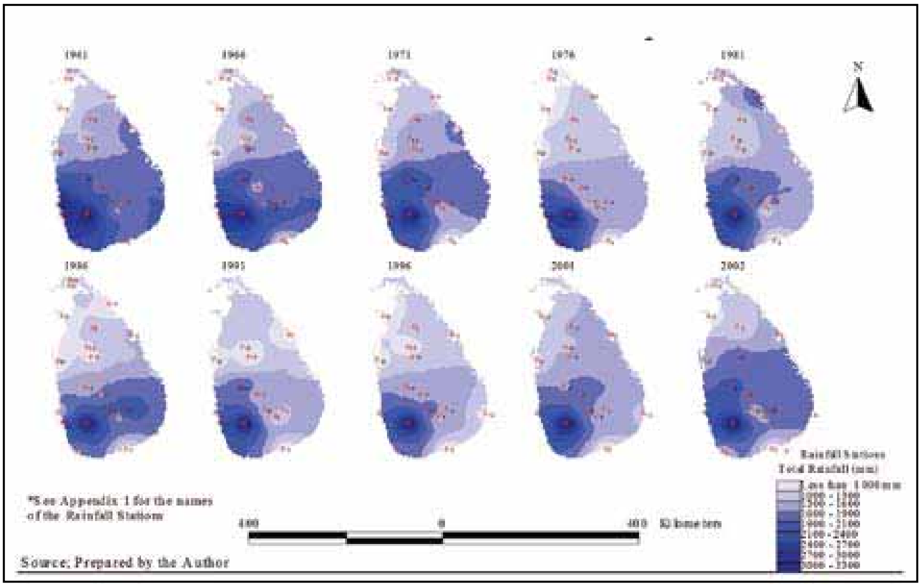


Spatial Analysis

Sri Lanka is an agrarian country and any shift in the climatic zones can have adverse agricultural and socioeconomic impacts. By observing the spatial changes in rainfall patterns, a clear perception can be obtained of the severity of the problems that may occur. The total rainfall data for each of the 22 rainfall stations were exported to Arcview GIS, and the rainfall data was interpolated for the 42-year period of each station, to examine the spatial changes in rainfall. From the interpolated surfaces, the variations in rainfall can be observed visually, as illustrated in Figure 9.

The total rainfall in the country has declined during the years of observation, especially in the north and south of the country (Figure 9). The area around Hambantota has experienced the greatest decline. The expanse of areas, which record a total rainfall below 1,600 mm, has gradually increased from 1961 onwards, but this expansion is more evident from 1971 onwards. By 1976, almost three quarter of the island, from Puttalam up to Galle, recorded a total annual rainfall below 1,600 mm. Also, from 1986, the stations in Kurunegala and Galle recorded a value below 1,600 mm in the majority of years. The southwestern quarter of the island recorded a total rainfall that was above 2,500 mm in 1961, with a few areas surrounding Potuvil also having recorded the same values of total rainfall. But from 1967 onwards, the area in the island recording total rainfall under 2,500 mm or less has declined steadily. The area that recorded a total rainfall of more than 2,500 mm in 1961 is concentrated in Colombo, Nuwara Eliya, Ratnapura, Galle, and even Kurunegala. In 1966 the area around Nuwara Eliya recorded rainfall less than 2,500 mm, but again in 1971, total rainfall increased to more than 2,500 mm. From 1971 onwards, again the Nuwara Eliya station recorded a total rainfall that was less than 2,500 mm until 1986, at which point it recorded a high aggregate of annual rainfall but again from 1991 onwards till the year 2002 it recorded a total rainfall that was less than 2,500 mm. Also, the area surrounding the southwestern parts of the island showed a decline in the total rainfall.

Figure 9. Rainfall distribution across Sri Lanka (1961-2002).



Investigating the Variations in the 'Crop Calendar'

The climatic variations across Sri Lanka mean that there is a need to study the spatial variation impacts of climate change on paddy cultivation.

Shifts in the Start and End of the Yala and Maha Seasons

The cropping calendars record the start and end of the *yala* and *maha* seasons for 25 years. Traditionally the *yala* season is cultivated from March to September (First Inter- Monsoon) and *maha* season from early October to February (South West Monsoon). Using the crop calendar the first days of the *yala* and *maha* seasons were analyzed to investigate whether these have changed over the years and whether they relate to water availability. As there is these dates are rarely recorded, the first and last days of irrigation water issues were taken as proxies. The amount of water issued and the total number of days that the water was issued were also considered.

Figures 10 and 11, respectively, represent the beginning and end of the *maha* season in the Kalawewa LB Reservoir, while Figures 12 and 13, respectively, represent the beginning and end of the *yala* seasons in the same reservoir.

Over the years a clear shift can be seen in the time at which the *maha* seasons started and ended in the Kalawewa LB Reservoir irrigated area. The *maha* season, traditionally starting from early October to February, has shifted to late October or sometimes to November and the harvesting days have moved to as late as March in most years, when it would traditionally have been considered to be February (Figures 10 and 11) The harvest only took place in February for 5 out of the 25 years that were recorded.

Figure 10. Kalawewa LB Reservoir's beginning day of *maha* season.

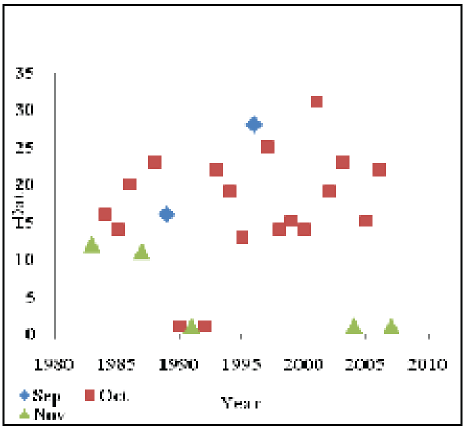
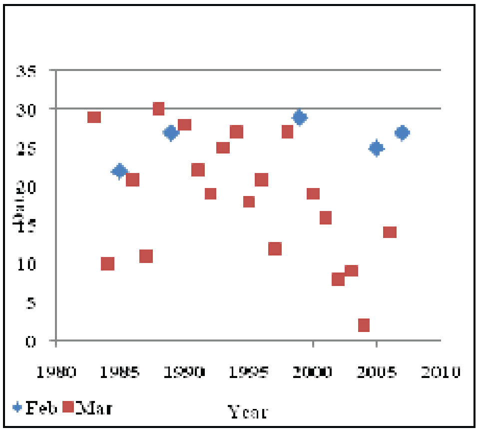


Figure 11. Kalawewa LB Reservoir's end day of *maha* season.



The *yala* season demonstrates an extreme case of transformation with the traditional start of the season shifting to April and in a majority of the years as May and June. This clearly reveals that the cultivation patterns in the country are now in the process of alteration (Figure 12). The end days of the *yala* season do not show any evidence of change (Figure 13).

Figure 12. Kalawewa LB Reservoir's beginning day of *yala* season.

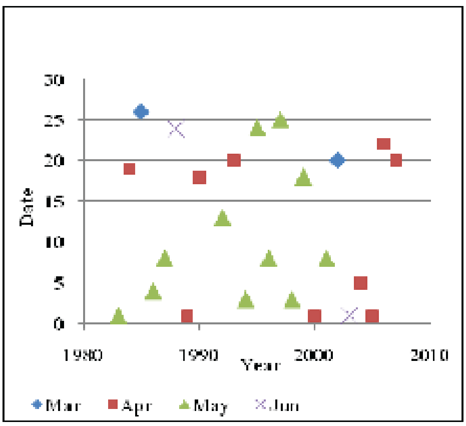
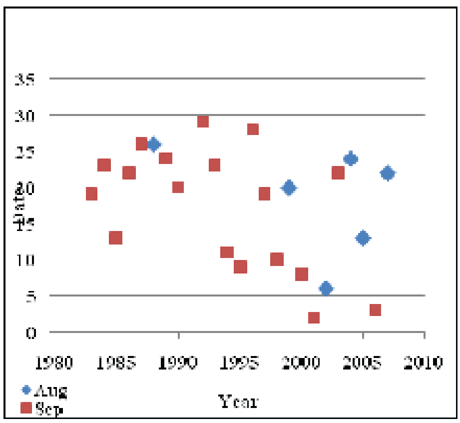


Figure 13. Kalawewa LB Reservoir's end day of *yala* season.



From the 15 reservoirs studied, 5 reservoirs (Maduru Oya, Kalawewa, Nachchaduwa, Nuwarawewa and Huruluwewa) demonstrate shifts in the *maha* cultivation days. Figures 14, 15, 16 and 17 illustrate the shifts in the beginning and end days of the *maha* and *yala* seaasons in the Huruluwewa.

Figure 14. Huruluwewa Reservoir's beginning day of *maha* season.

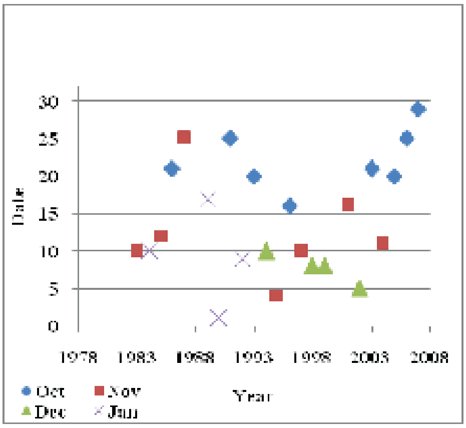


Figure 15. Huruluwewa Reservoir's end day of *maha* season.

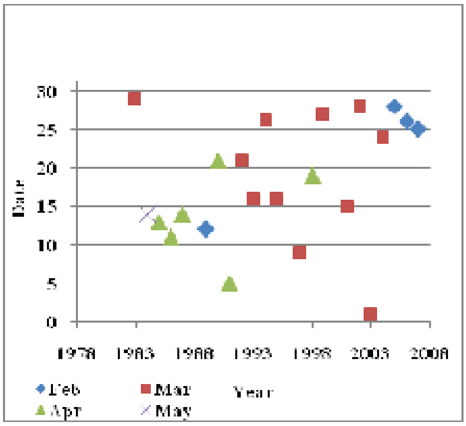


Figure 16. Huruluwewa Reservoir's beginning day of *yala* season.

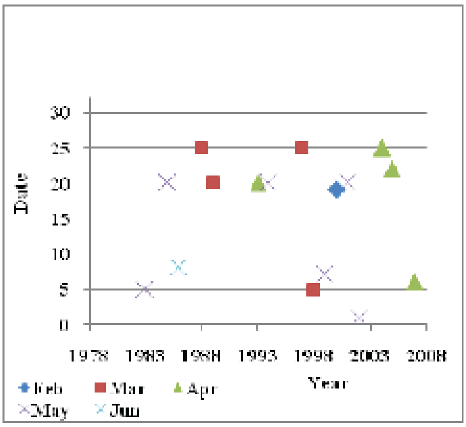
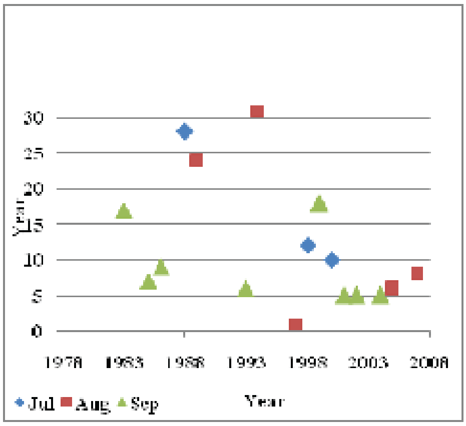


Figure 17. Huruluwewa Reservoir's end day of *yala* season.



High variation is recorded for the start time of *maha*, in the period of the study, with the start days shifting from the traiditional month of October, to November and December and in some years, as late as January. The end days of the *maha* season show an extreme shift from February, to March, April, and May. During the last 10 years, the start has shifted to late October and even early November. The *yala* season also demonstrates variations like in all other reservoirs but the end days of the *yala* season do not show any specific alteration, except for ending in periods earlier than in other reservoirs under study.

In all 15 of the reservoirs studied, the most pronounced shift in the cultivation pattern is observed in the *yala* season, with the beginning of the season shifting to April and in some years to May as well. But the end days of *yala* do not show a shift.

Variations in Water Issues and the Number of Water Issue Days in Yala/ Maha

During the period of the study, there has been a variation in the number of days in which water is issued. From the early 1990s onwards, a declining trend is observed for both seasons. In most of the reservoirs taken studied, the number of days on which water is issued has fallen below 160 days from the early 1990s as seen in figures 18,19,20 and 21.

Figure 18. The number of days in which water is issued in the Kalawewa LB Reservoir during the *maha* season.

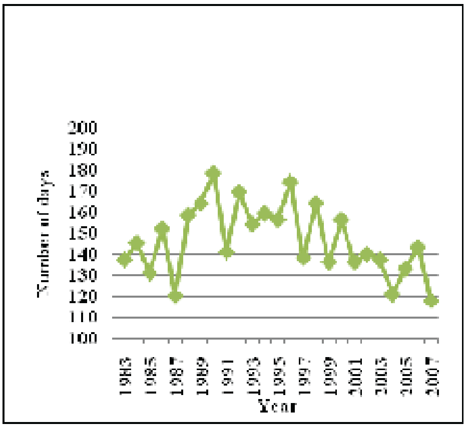


Figure 19. The number of days in which water is issued in the Kalawewa LB Reservoir during the *yala* season.

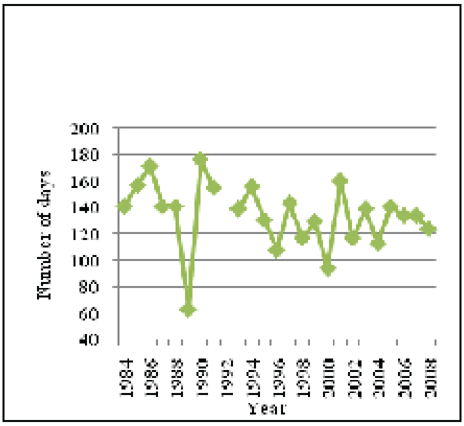


Figure 20. Amount of water issued in the Kalawewa LB Reservoir during the *maha* season.

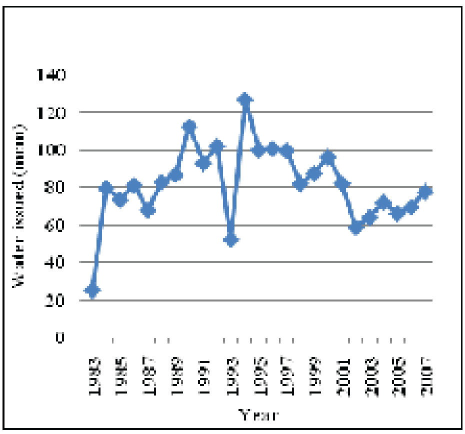
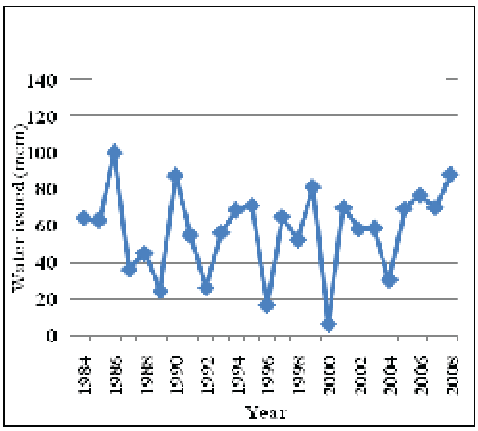


Figure 21. Amount of water issued in the Kalawewa LB Reservoir during the *yala* season.



As regards the amount of water issued from the Kalawewa LB Reservoir in both cultivation seasons, the water volume has increased slightly during the past 25 years but there are large variations, especially in *yala*.

In the Parakrama Samudraya Reservoir, the number of days in which water is issued has also declined throughout the years during both the *maha* and *yala* periods, but the amount of water issued has actually increased slightly overall (Figures 22, 23, 24 and 25).

Figure 22. The number of water issued days in the Parakrama Samudraya Reservoir in the *maha* season.

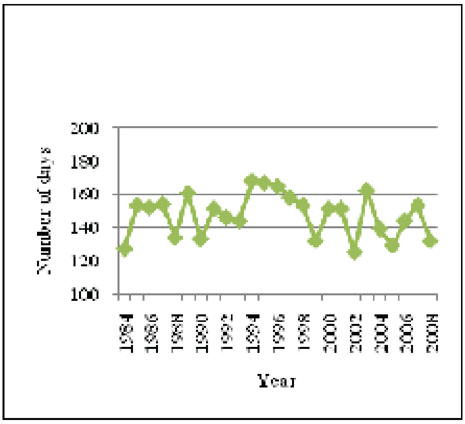


Figure 23. The number of water issued days in th Parakrama Samudraya Reservoir in the *yala* season.

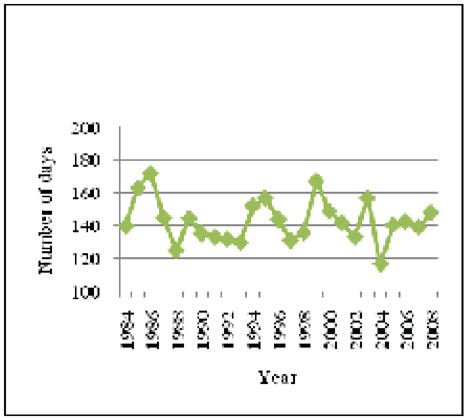


Figure 24. Amount of water issued in the Parakrama Samudraya Reservoir in the *maha* season.

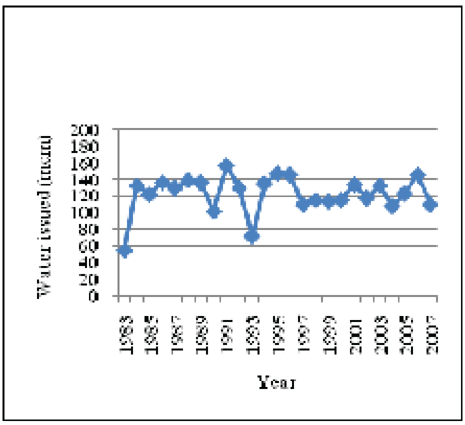
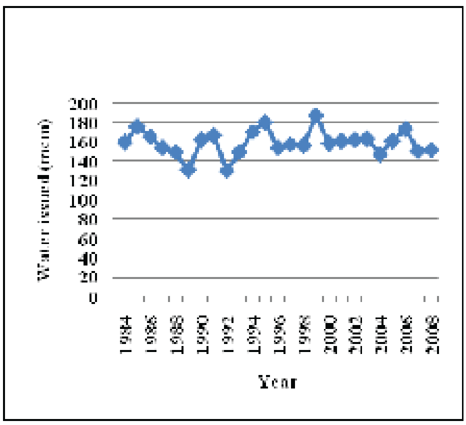


Figure 25. Amount of water issued in the Parakrama Samudraya Reservoir in the *yala* season.



Note: The area of cultivation is constant during the period of study

In all the 15 reservoirs under study, the number of days in which water is issued seems to be declining, with the days declining below 150 days after the 1990s in both the *yala/maha* seasons. However, the amount of water issued has increased in some reservoirs, especially during the *yala* season. Girithale, Minipe, Ulthitiya Rathkinda, Huruluwewa, Udawalawe LB, Maduru Oya and Parakrama Samudraya show slight increases in the amount of water issued in the *yala* season, while Minipe, Ulhitiya Rathkinda, Maduru Oya, Kalawewa LB, Parakrama Samudraya and Udawalawe LB recorded a slight increase in the amount of water issued in the *maha* season. The amount of water issued has only increased slightly and it has not affected the starting days of *yala* season.

Conclusion

The study found that although the number of rainy days has declined at all, but one, of the meteorological stations, the annual total rainfall has not declined in all the stations. The total annual rainfall has actually increased in the Jaffna, Potuvil and Mullaitivu stations, but has declined in all the other stations in the dry, intermediate, and wet zones. The spatial analysis highlights this decline in total anual rainfall as the areas with high rainfal (over 2,500 mm per year) have reduced and are now limited to the southwestern parts of the central highlands. The lowlands of the southwestern parts of the island record a declining expanse of the area recieiving total rainfall in the amount below 2,500 mm. This could indicate that the intensity of rainfall events may have increased and that the duration of dry spells has inceased, especially in the dry zone. Further studies are needed to investigate the relationship between the numbers of rainy days and total rainfall within seasons.

The changes in the ‘Crop Calendar’, which indicate a shift in the start and end of the cultivation seasons, show that there are delays in the arrival of rainfall and a reduction in the number of days in which water is issued from the irrigaiton scheme This data provides evidence that droughts and dry spells can affect paddy cultivation practices. Further studies are needed to investigate the delays in seasonal rainfall and the impact of such delays. Such studies could provide invaluable guidance to decision-making in agricultural practices and water management.

References

Kankanam, B. N. U. S.; Punyawardana, B.V. R.; De Silva, R. P. 2007. ‘Recent Variability of Southwest Monsoonal Rainfall over Sri Lanka’, Symposium Proceeding of the Water Professionals Day, October 01, 2007. Water Resource Research in Sri Lanka. B.M.I.C.H., Colombo, Sri Lanka.

Thambaiyapillay, G. 1954 ‘Ceylon and the World Climatic Mosaic, University of Ceylon Review’, Volume XIII (Jan.) Ceylon.

Yoshino, Masatoshi M.; Suppiah, Ramasamy. 1984 ‘Rainfall and Paddy Production in Sri Lanka’, page 9-20. http://rms1.agsearch.agropedia.affrc.go.jp/contents/JASI/pdf/society/29-1789.pdf. November 27, 2008. 11.20 a.m (Oct 25, 2008, 10.35 a.m.) www.irinnews.org/Report.aspx?ReportId=77549 (April 1, 2008, 11.37 a.m.)

Climate Change and Rain-fed Agriculture in the Dry Zone of Sri Lanka

C. R. Panabokke and B. V. R. Punyawardena

General Background

A study conducted by the International Rice Research Institute (IRRI) in collaboration with Sri Lanka's Rice Research Program of the Department of Agriculture (DoA) in 1981 was able to bring out the inherent degree of variability in rice production (both irrigated and rain-fed rice) in this country; and to make a comparative evaluation of this variability with other rice growing countries in the Asian region. A summary of the findings of this study is shown in Table 1, and the implications of these findings are discussed below.

Table 1. Variability in staple food production (1970-1980).

Country	Coefficient of variation (%)	Probability of actual production falling below 95 % of trend
Indonesia	5.4	18
Philippines	5.7	19
Bangladesh	6.4	22
India	6.4	22
Sri Lanka	9.3	29

Climatic Seasons of Sri Lanka

Climatologists have indentified four main seasons into which the climatic year of the country could be sub-divided, as shown in Table 2.

Table 2. Climatic seasons of Sri Lanka.

Season	Effective period	Rainfall (mm)	Percentage contribution
First Inter-monsoon	March to mid-May	368	14
South West monsoon	Mid-May to September	556	30
Second Inter-monsoon	October to November	558	30
North East monsoon	December to February	479	26

During the first inter-monsoon season the island is dominated by the diurnal rhythm of convectional air circulation associated with the Inter-Tropical Conveyance Zone (ITCZ), and it is also relatively free from the larger meso-regional transfer of air masses associated with global wind belts. The early stages of this season are dominated by dry weather in most parts of the country, except in the southeast where convectional circulations generate thunderstorms. As the season progresses, there is a gradual increase of rainfall, which can be attributed to the frequent occurrence of westerly air currents in the lower atmosphere; and this gives rise to what is described as the 'early surges of the South West monsoon' by Thambyahpillay (1955). These pre-monsoonal rains are largely confined to the southwestern parts of the country.

The onset of the South West monsoon usually in the latter half of May marks the commencement of enhanced rainfall in the southwest parts of the country. However, because of the pre-monsoon rains that precede this onset, the so-called 'burst' of the monsoon is less spectacular than in most parts of the Indian sub-continent. In the lower elevations of this country, this monsoon rain occurs in typical spells, but the intensity and duration of these rainy spells tend to increase in the higher elevations. By contrast, the north, north-central, eastern and southern segments of the country all fall within the rain shadow of the southwest monsoon during this period, and thereby experience dry to very dry conditions from mid-May to September. The dryness associated with the low rainfall in these areas is further enhanced by the desiccating föhn effects of the monsoonal air currents in the leeward aspects of the country's highlands. As a result, the sharpest regional contrasts of climatic conditions within the country are experienced within the season of the southwest monsoon from May to September.

Contrary to the popular perception that the South West monsoon is associated with the wettest period of the year, it is in the second inter-monsoon season that Sri Lanka records the highest monthly totals of rainfall. In the months of October and November, rainfall occurs almost uniformly across the whole country and regional contrasts in rainfall are thereby substantially reduced. The extensive occurrence of rain during this second inter-monsoon season is primarily due to the frequent movement of tropical depressions across the island, and also in part due to the air currents associated with the later surges of the southwest monsoon.

The depressional rains of October and November are a prelude to the commencement of the North East monsoon season. The heavier rainfall, which is confined to the eastern half of the country, gradually decreases from December to February. In December, the prevalence of easterly wind streams and cyclonic wind circulations could give rise to the spells of heavy rain on the eastern slopes of the highlands. The orography of the area also causes steady rains in the eastern slopes of the highlands. By February, which is the driest month of the whole country, there is a distinct waning of the effects of the North East monsoon, and a gradual re-establishment of weather conditions typical of the Inter-Tropical Conveyance Zone (ITCZ).

Variability of Seasonal Rains

In order to characterize the nature of variability of the four respective climatic seasons for the country, the coefficients of variation for two 30-year periods, namely, (a) 1930 to 1960 and (b) 1960 to 1990, were calculated, and the results are presented in Table 3.

Table 3. Variability of seasonal rains for two 30-year periods.

Season	Coefficient of Variation	
	1930-1960	1960-1990
First Inter-monsoon	31	42
South West Monsoon	23	27
Second Inter-monsoon	21	16
North East Monsoon	22	23
Annual	11	14

As can be seen in Table 3, the greatest change for the two respective 30-year periods took place during the first inter-monsoon season, which is associated with the ITCZ from the month of March to mid-May.

As discussed in the previous section of this paper, this first inter-monsoon season is strongly influenced by the nature of the convectional air circulation associated with the ITCZ and also by the pre-monsoonal rains of the southwest monsoon. Hence, it is susceptible to a greater degree of variability than the other three component seasons.

As can be seen in Table 3, it is the fourth season, namely the northeast monsoon season that shows the lowest degree of variability; and this is followed by the second inter-monsoon season.

Some Main Characteristics of Rain-fed Agriculture in the Dry Zone of Sri Lanka

Traditionally, and even from ancient times, rain-fed agriculture in the dry zone of Sri Lanka had been practiced during the 4-month period from October to January. This corresponds to (a) the second inter-monsoon season and (b) the northeast monsoon season, as shown in Table 2, which together account for 56 % of the annual rainfall. At the same time, as could be seen in Table 3, these two seasons also show a lower magnitude of change for the two respective 30-year periods. It is, therefore, reasonable that the traditional Maha cropping season in Sri Lanka has coincided with this favorable 4-month period from October to January.

Despite the foregoing conditions, agriculturists have long recognized the very high annual variation in the yield of rain-fed arable crops in the dry zone environment of Sri Lanka. Even prior to the advent of climate change in this country, the very high annual variation in the yield of rain-fed arable crops in the weakly poised rainfall systems of Sri Lanka's dry zone had been recognized by several agricultural scientists, especially those stationed in the different districts of this country's dry zone.

Abeyratne (1962) had clearly brought out the essential nature of this variation when he showed that over a 25-year period at Maha Illuppallama, rain-fed rice yields had ranged between 74 to 8 lb/acre, while over a 12-year unbroken period, rain-fed cotton yields had ranged between 1,120 to 220 lb/acre. He further showed that almost the whole of this variation could be ascribed to the chance of obtaining a satisfactory trend in soil moisture during the growing season.

In order to even out these wide fluctuations in yield, and to also stabilize rain-fed farming in the dry zone, Panabokke (1974) had proposed a stringent analysis of the real nature of the variability in the main maha season rainfall, and to then specify (a) proper choice of sowing dates, and (b) a selection of optimum 'sowing-to-harvest' duration or 'age-class' of the main crops so that there could be a maximum likelihood of the rainfall satisfying the 'crop water' demand at every stage of its growth and development.

Confidence Limits of Expected Rainfall and the Application of these Limits to Crop Water Requirements

In tropical regions in particular, it has been shown that the statistic of mean monthly rainfall even when derived from data compiled over a large number of years, is at best an unreliable guide to the variation in rainfall with which the agriculturist must contend. The arithmetic mean that is usually calculated directly from the rainfall figures does not take into account this inherent skewness of the raw data, and the fact that the data accounts for a disproportionately large amount of rain falling in heavy tropical downpours, thereby raising the level of the mean much above the normal amount of rain received or expected. Thus, unless account is taken of the skewness of the frequency distribution of the rainfall where the mode is lower than the mean, estimates of rainfall expectancy made directly from raw data could be quite misleading.

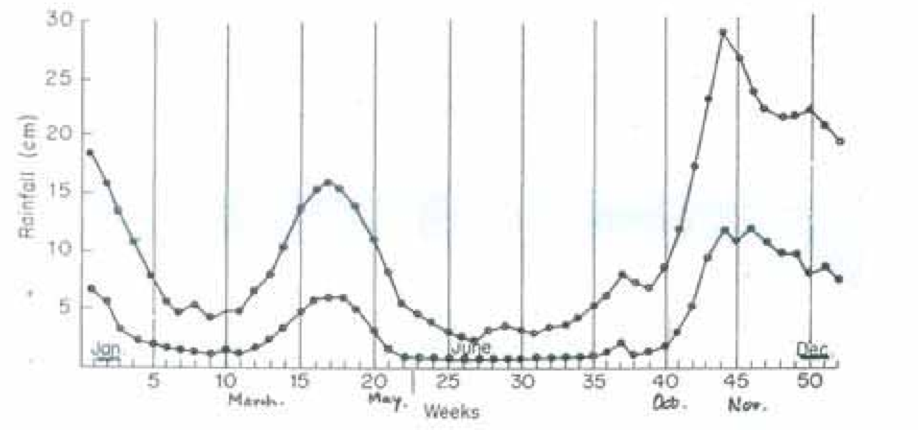
It has been show by Alles (1971), that for the months of October, November and December, both weekly and monthly rainfall values show a non-normal positively skewed distribution pattern. Clearly, any statistic derived from such distribution will give a distorted mean of the real values. Several methods are available for transforming skew data to give approximate normal distributions. The method proposed by Manning (1956) was used in this study, and the method provides a 'completely objective and reliable estimate of rainfall to be expected, which is not apparent when means alone are used.'

By matching the crop water requirements against the 1:1 confidence limits of rainfall, it was possible to propose the age-class for any particular crop so that its water demand fitted as closely as possible with the probable seasonal supply of soil moisture.

The manner of fitting sowing data and the age-class of crops to rainfall expectancy will be outlined.

The confidence limits of the three weekly moving totals for Maha Illuppallama rainfall are shown in Figure 1. The minimum expectation for 3 years in 4 is given by the lower limit.

Figure 1. Confidence limits of three weekly moving totals of Maha Illuppallama rainfall.



Rain-fed Crop Performance for the Period 1978 to 1987 Compared with Period After 1989

Four rainfall stations in north-central Sri Lanka, which had an unbroken record of 25-years of rainfall, were selected for working out 3 weekly moving totals of 1:1 confidence limits of rainfall. Selection of optimum sowing dates, as well as optimum 'sowing-to-harvest' duration, of different crops was then proposed by Panabokke (1974). A field testing and validation of the proposed 'time-of-sowing' as well as the 'sowing-to-harvest' duration of the main coarse grain and grain legume crops, was carried out in collaboration with the Extension Division of DoA of the north-central province (NCP) in collaboration with the Regional Technical Working Group (RTWG) of the NCP over the period 1975 to 1979.

An adoption of these recommended dates of sowing as well as the age-class of the commonly grown rain-fed crops resulted in a significant stabilization of the seasonal performance of these crops throughout the 9-year period of 1978 to 1987.

However, from the year 1989, it was reported by Panabokke that an unprecedented aberration in the seasonal patterns of rainfall had been taking place to the extent that the August/September rainfall of 1986 had fallen even outside the 90 % confidence limits. Furthermore, as elaborated by Panabokke (1989) in his presentation titled 'Potential Impact of Climate Change on Agricultural Production in Sri Lanka,' it was stated that "up to 1987 it is observed that both 'within' season as well as 'between' season variation in rainfall could be statistically accommodated within the 1:1 confidence limits of expected rainfall on a weekly basis." However, after the year 1988, it is stated that the rainfall in the main season October-January was becoming more variable and more extreme, thus resulting in a destabilization of rain-fed agriculture, especially in the dry zone of the country. In effect, the popular dictum that 'the past is a key to the future' is no longer applicable because what will happen in the future is no more conditioned by what happened in the past.

The Contemporary Condition of Rainfall Variability in the Dry Zone

In order to bring out the contemporary condition in respect of rainfall variability in the dry zone, the 95 % confidence intervals of weekly rainfall for the years of 2006, 2007 and 2008 for two selected stations in the north central and southern dry zones, namely Maha Illuppallama and Weerawila, were analyzed. The results, which are presented schematically, show that for the period between the 40th and 52nd week, a drastic degree of aberration could be observed. In other words, extreme events are now the normal pattern, rather than the rare occasion they were in the past.

Correspondingly, severe aberrations in seasonal crop production in respect of the maize and cowpea crops have also been recorded.

References

Abeyratne, E. 1962. Proceedings Ceylon Association of Advancement in Science 18 (2) 58-72.

Alles, W. S. 1971. *Tropical Agriculturist* 77, 11-21.

Manning, H. L. 1956. Proceedings of the Royal Society, B, 144, 460.

Panabokke, C. R. 1974. *Journal of the National Science Council of Sri Lanka* 2 (2): 95-113.

Panabokke, C. R. 1989. Symposium on Climate Change, Ministry of Environment 45-49.

Thambyahpillay, G. 1955. The Rainfall Rhythm of Ceylon. University of Ceylon.

Climate Change, Local Institutions and Adaptation Experience: The Village Tank Farming Community in the Dry Zone of Sri Lanka

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Abstract

Farmers are in a continuous process of, individually and as community groups, adjusting to the observed variability in climate parameters. Climate shocks are considered by farmers in their decision-making as factors affecting risk and uncertainty, and farmers make their choices so as to minimize such risks. The overall outcome of these individual and community efforts is known as 'climate adaptation', which itself is a continuous process. Farmers are traditionally supported by local institutions in this process, which are also currently in a state of transformation. This study examines the climate adaptation responses of the village tank farming community in the dry zone of Sri Lanka in the context of transforming socioeconomic conditions and with the objective of identifying policy implications for adaptation to global climate change. The study was conducted in six Divisional Secretariat areas in the Anuradhapura District of the North Central Province. Both, primary and secondary data was collected in the study. The major sources of primary data included a series of focus group discussions and key informant interviews conducted with village tank farmers and local officers.

The findings reveal that there are two major forms of voluntary adaptation responses by farmers against climate shocks: 1) aligning of farming activities with the recognized seasonal pattern of rainfall; and 2) management of rain water harvested in commonly owned village tanks. Farmers' adaptation responses have been facilitated by local institutions that helped to adopt joint adaptation responses. However, recent socioeconomic dynamics introduced by rapid population increase, spread of commercial opportunities and change in agricultural technology have drastically altered conditions in the village tanks in favor of developing a commercial farming system. As a result, local institutions that traditionally facilitated the climatic adaptation responses are also in a state of transition. Therefore, farmers face problems in adapting to the impending risks and uncertainties of global climate change. The paper emphasizes the need for appropriate policy measures to facilitate the adaptive capacity of farmers.

Introduction

Farmers are in a continuous process of adjusting to various changes taking place in the environment around them. Among others, adjusting to changes in weather and climate parameters is a fundamental condition for their livelihood security. Any observed change in climate parameters, regardless of whether it is a result of natural process or human activity, has the potential to affect farmers' livelihoods in an unforeseen manner. From the point of view of farmers, any change in climate parameters with known or unknown probability can be considered to be climate shocks. Climate shocks enter farmers' decision making processes as matters of risk and uncertainty. Farmers select their choices with the objective of minimizing the risk and uncertainty of outcomes under the influence of climate shocks. Their choices may include individual (private) as well as joint efforts as community groups to minimize adverse effects of climate shocks on their livelihoods. The overall outcome of these individual and community efforts is known as 'climate adaptation', which itself is a continuous process. In the process of climate adaptation farmers accumulate a wealth of experience and knowledge, which helps in further optimizing their choices against climate shocks. Therefore, climate adaptation is an evolutionary process.

In the process of climate adaptation, farmers have created local institutions that help to govern the actions of individuals as well as community groups. In addition, communities have developed facilities that enhance their adaptation efforts over the long run. Usually, these 'adaptation support facilities' also were governed by local institutions. In the developing country context, such local institutions still continue to play an influential role in farmers' decisions on adaptation. However, broad, sweeping forces that transform traditional farming contexts, such as increasing population, rapid commercialization and 'modernization' of technology, have had a tremendous impact on the traditional roles played by such institutions. As a result, the impact of these transformations introduces a complex socioeconomic dimension to the climate adaptation process.

Village tank farmers in the dry zone of Sri Lanka are a fine example of how a community should respond to the challenge of climate adaptation under extensive socioeconomic transformation. Successive governments in Sri Lanka have invested massive public funds in irrigation projects to improve the situation of water scarcity faced by the dry zone farmers (Aluwihare and Kikuchi 1991; Kikuchi et al. 2002). Despite such efforts, a significant population of small village tank farming communities still lives under the constant pressure of water scarcity. Regardless of the support received from village tanks, which are essentially a network of community-managed rainwater harvesting devices, farmers in such communities basically depend on local rainfall for their livelihood needs. Many problems faced by farmers are almost certain of being aggravated in the future given the looming uncertainties of climate change. Compared with their counterparts in major irrigation schemes, village tank farmers are naturally more vulnerable to climate change due to the high dependence of their farming systems on local rainfall. Hence, the small village tank farmers in the dry zone deserve the priority attention of policymakers when the latter are deciding adaptation strategies to face the challenges of global climate change.

This paper attempts to examine the climate adaptation process of village tank farmers with the aim of identifying important policy implications that can enhance the adaptation responses to the impending threat of global climate change. Specific objectives of the study include the following:

- Examine the climate adaptation process of the village tank farming community
- Investigate socioeconomic changes involved in the process of climate adaptation and their impact
- Identify important implications for policies on adaptation to global climate change

Method

The Study Area

The study was carried out in the Anuradhapura District of the North Central Province. Primary data was collected from farmers and local officers from six Divisional Secretariat (DS) areas, namely; Thirappane, Sivalakulama, Mihinthale, Galenbindunuwewa, Kahatagasdigiliya and Andiyagala. A profile comparing the water and land resources of the Anuradhapura District is provided in Table 1.

Table 1. A profile of water and land resources in the Anuradhapura District.

Parameter	Sri Lanka	Anuradhapura District (%)
Land area (km^2)	65,610	7,179 (11 %)
Inland waters (km^2)	2,905	515 (18 %)
Average annual rainfall (mm)	1,861	1,368
Equivalent water volume (b m^3)	120	9.6 (8 %)

Source: Department of Census and Statistics (2007)

Data and Methods

Both primary and secondary data were collected in the study and the following methods were used to collect the data.

- Focus Group Discussions (FGDs) were conducted with farmer groups of 10-15 in size, from the selected DS areas. Discussions were held using a semi-structured, yet flexible focus guide. The discussions inquired about the physical profile of the resources in the villages, about the farming systems, local water management, formal and informal institutional arrangements, experience in climate change and adaptation measures to face the changes and variability in climate.

- Key Informant Interviews were conducted with local officers and a few experienced farmers. Local officers included divisional and village level officers. These interviews and discussions, supplemented the information collected from farmers and helped to recognize the views and perspectives of local officers who are involved in local resource management in the area.

- Secondary Data were collected from a number of key institutes, which have either conducted important studies in the past or which undertake mandatory institutional responsibilities relating to the research issues concerned. The major types of secondary data collected include: information on water scarcity; hydrological and water balance studies; rainfall and other meteorological data; physiographic information of resources; and studies on socioeconomic and institutional aspects.

Analysis

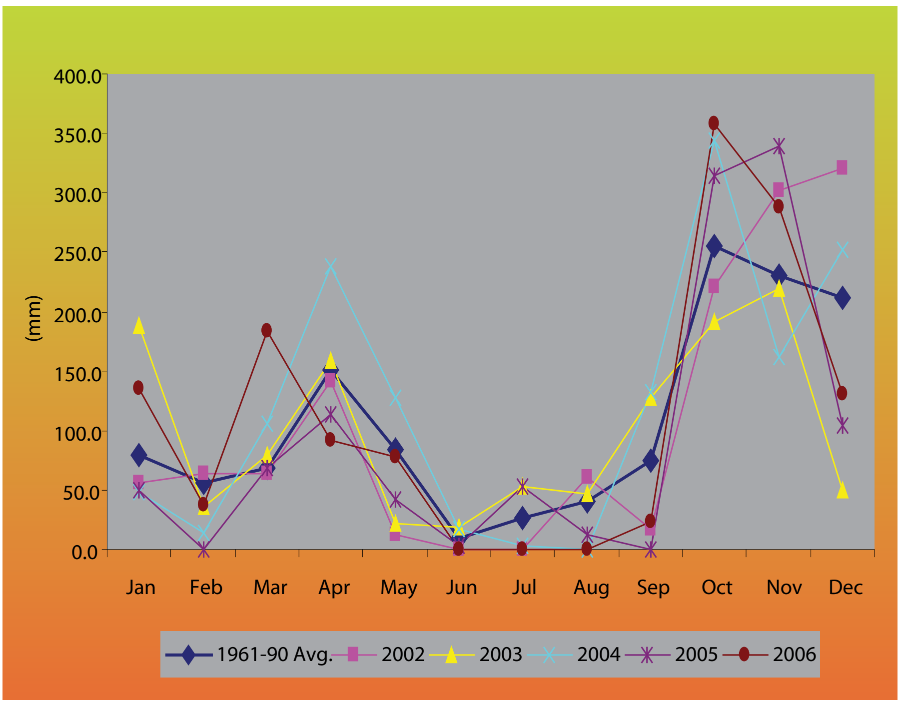
Given the exploratory nature of the data involved, a qualitative analysis of data from various sources was undertaken. This basically involved a comparative assessment of information obtained from different primary and secondary sources. Complex, statistical or quantitative analyses were not made, other than the calculation of percentages and averages, and the comparison of their results.

Results and Discussion

Climate Shocks and the Scarcity of Water Resources

The key to understanding the climate adaptation strategy of farmers in the area is to examine the pattern of climate variability and resulting outcome of water availability in the area. Figure 1 indicates that Anuradhapura District has a bi-modal rainfall (RF) pattern, with a prominent peak during the October-December period followed by a minor crest in the month of April. On average, 74 % of the annual RF is received during the period from October to March.

Figure 1. Rainfall distribution pattern in Anuradhapura.



Sources: Department of Meteorology and Department of Census and Statistics (2007)

Accordingly, two major forms of climate shocks can be identified: 1) shocks due to major dry spells that can be recognized in the average pattern of rainfall and; 2) random shocks due to unexpected changes in the average pattern of rainfall. The former can easily be recognized in Figure 1 in the period from May to September, when the entire area (with minor local variations) experiences a lengthy dry spell. This is the major climate shock that determines the situation of water scarcity in the area and farmers have some idea about the probability of this event (Tennakoon 1986). Table 2 provides a projection for the district as regards the severity of the general effect created by this major shock in terms of water scarcity (Amarsinghe et al. 1999). As discussed later, the main strategy of climate adaptation in village tank systems has evolved to face the threat of this climate shock.

Table 2. Water scarcity projections for Anuradhapura District.

Scarcity indicator		*Yala* (dry season)	*Maha* (rainy season)
UN indicator	1991	Severe	Severe
	2025 – Scenario 01	Severe	Severe
	2025 – Scenario 02	Severe	Severe
IWMI indicator	2025 – Scenario 01	Severe absolute	Severe absolute
	2025 – Scenario 02	Severe absolute	Little

Notes: Efficiency of the irrigation remains at the current level (S1); Irrigation efficiency improves over the project period (S2)

The second type of climate shocks that can be identified is random in nature and farmers have little idea about the probability of the occurrence of such shocks. Such shocks, therefore, can be considered as extreme deviations from the average pattern. Two visible examples in Figure 1 show that relatively high RF was received in Feb-Mar 2006 during the harvesting period and a low intensity of RF took place during the Oct-Nov period (peak period of the rainy season) in 2003.

Farmers' Adaptation Strategies against Climate Shocks

Farmers have historically adopted two major adaptation strategies to face the major shock of lengthy dry spells, which are observed in the average rainfall pattern of the dry zone. The strategies are: (a) aligning farming activities with the recognized seasonal pattern of rainfall to make the maximum use of water directly available from precipitation; and (b) joint adaptation through the management of rainwater harvested in communally owned village tanks.

Aligning Farming Activities with Recognized Seasonal Rainfall Patterns

Farming under direct rainfall is the least costly option for water supply in the area. However, such a source of water carries some risk due to the uncertainty of RF. Farmers, through their generations of experience, adjusted farming activities to be aligned with the seasonal pattern of rainfall so as to minimize the risk associated with farming under direct rainfall.

Accordingly, two major cropping seasons, *maha* and *yala* have evolved in the farming system of the dry zone. *Maha*, from October to March, is the main cultivation season supported by the north-east monsoon, the major source of water for the dry zone. The *yala* season or the dry season, from April to September, has no major period of rainfall other than a few intermittent rains.

Table 3 highlights the farming system and water management strategy that has historically evolved in the village tank systems. It included both purely rain-fed upland cropping activities and irrigated paddy farming (Somasiri 2001; Handawala 2004). The two major components of upland farming were the cultivation of seasonal field crops under shifting cultivation ('chena' farming) in the *maha* season and mixed farming of seasonal and permanent crops in homestead gardens (Abeyratne 1956; Weerakoon et al. 1987). Lowland paddy cultivation in the *maha* season partially depends on RF during the early stage of crop growth.

According to farmers' experiences, the probability of rainfall varies in different periods of the annual cycle. As a result, farming activities that are aligned with periods of high rainfall probability have become more stable components of the farming system. For instance, farmers consider extensive cultivation of gingelly under inter-monsoon rains with low probability as a high-risk activity and, therefore, the cultivation of gingelly remained a less stable activity in the system. Therefore, data on farming activities, taken from different periods of the annual cycle, indicate farmers perceptions of risk.

Table 3. Traditional farming system with water management strategy.

Farming system activity	Crops	Seasonality		Water supply		Location	Economic status
		Maha	*Yala*	*Maha*	*Yala*		
Lowland farming	Paddy	All plots in the field	Limited area	Rain-fed + tank water	Tank water	Command area of village tanks. Bethma in yala	Mainly subsistence with limited sales if a surplus is available
Upland farming	Coarse grains, grain legumes, pulses, vegetables, condiments, gingelly	1-5 ac avg. by all HH	Gingelly	Fully rain-fed	Fully rain-fed	Shifting agriculture in commonly owned uplands	Mainly subsistence with few cash crops
Permanent crops	Coconut, fruits, multi purpose trees	No seasonality		Rain-fed + retained moisture in soil		Home gardens	Mainly subsistence with few cash crops

Joint Adaptation with the Support of Commonly Owned Village Tanks

Small village tanks have historically been constructed to counteract the problem of temporal scarcity of water due to lengthy annual dry spells. From the point of view of climate adaptation, village tanks can be identified as the most important 'adaptation support facility,[1] available to

[1] In the same sense, major irrigation facilities consisting of large storage reservoirs, trans-basin diversion structures and network of distribution canals can also be considered as adaptation support facilities available to farmers in settled irrigation schemes. However, this is a result of planned adaptation supported by the state rather than an outcome of voluntary adaptation by farmers.

farmers. It has been estimated that there are over 12,000 village tanks scattered throughout the dry zone areas of the country (Panabokke 2001). The Anuradhapura District alone has over 2,500. Some of the tanks date from the earliest era of the country's human settlement (Siriweera 1994). An important observation to be made here is that a large proportion of these inland water bodies are seasonal in their nature, in that water is available only for a limited period of time during the year (Chakrabarty and Samaranayake 1983).

Water stored using village tanks, helps to minimize and offset the risk of seasonal water scarcity through the community management of tanks. This can be considered as a historical joint adaptation measure taken by farmers to minimize the risk of temporal water scarcity during the dry spells. Compared with the relatively costless supply of water from direct rainfall, this measure incurs some transaction cost. In the local farming system, tanks seem to fulfill two major functions. First, they support the maha season paddy crop, which is usually established with the northeast monsoon rainfall but requires supplementary irrigation later in the season. Second, they enable at least a part of the paddy lands to be cultivated in the dry season also, depending on the level of water availability in the tanks.

Common ownership of village tanks has facilitated unique arrangements of joint adaptation under high water scarcity conditions. For instance, in the *maha* season when there is adequate RF, individual farmers are entitled to cultivate their plots of paddy as private lands under a common schedule of water management. However, during the water-scarce yala season, the private rights are suppressed in the common interest of food security for the whole community under an institutional arrangement called bethma (the division). On such occasions, community members collectively decide the total area of paddy land that can be physically supplied by the limited water available in the tank, and divide this land among all the members of the community regardless of the ownership of the respective land plots. In other words, individuals have to make a trade off between privately held rights over land and commonly held rights to water under conditions of scarcity. This can be considered a unique social benefit of joint adaptation.

Facing the Random Shocks Caused by Changes in Average Rainfall Pattern

Aligning farming activities with the seasonal patterns of the climate and community management of rainwater harvested in village tanks helps farmers to also buffer random shocks to a certain extent. In addition, farmers seem to fine-tune their cultivation practices even within the season, depending on the water availability. Researchers have made observations that every season farmers adjust their farming activities, responding to the intra-seasonal variability of the climate to a certain extent (Tennakoon 1986). According to Handawala (2004), the intensity of daily rainfall and distribution of rainy days within the season have more influence over the determination of cultivation practices than the total rainfall within a season.

Climate Adaptation and Local Institutions

In essence, adaptation to climate variability is closely interconnected with institutional arrangements dealing with allocation, distribution and utilization of the limited supply of available water. Village tanks are common property resources (CPR). The user rights for water in commonly owned village tanks are usually held by well-defined agrarian communities who own or cultivate paddy fields in the command areas of tanks. They make decisions on the use of tank water through an institutional mechanism that involves Farmer Organizations (FO).

However, three macro-scale processes are rapidly transforming the socioeconomic conditions in the village communities surrounding the tanks, these are: population growth; commercialization of local economies; and 'modernization' of agriculture technology, (Panabokke 2001; Aheeyar 2001; Ulluwishewa 1997). As a cumulative result of such change-agents, ownership and tenure patterns of village resources associated with the village tank system have undergone significant changes during the recent past. In the traditional system, collective actions were taken in several aspects of the farming system and a set of informal, customary practices governed the many aspects of managing local resources (Ulluwishewa 1997). The commercialization of the traditional farming system, however, has rendered many such traditional institutions ineffective. As a result, effective utilization of community-based institutional arrangements for climate adaptation seems to be gradually declining. Instead, private adaptation measures under the commercial farming system are becoming more and more popular.

The most prominent private adaptation measure is the utilization of groundwater from shallow regolith aquifers in the area through agro-wells. Agro-wells enabled farmers to tap the shallow groundwater storage in addition to the surface storage in the tanks, thereby further reducing the risk of water scarcity. Despite the fact that the groundwater aquifer is a 'common pool' resource, access to groundwater is determined by the ownership of the land plots above the aquifer. As no rules or regulations are in place to govern the actions of individual agro-well owners, groundwater can be considered a type of unregulated common property.

Groundwater from Agro-wells: Private Adaptation under Commercial Farming

Compared with the historical village tanks, extraction of groundwater through agro-wells is a recently adopted private adaptation measure that became popular during the last two or three decades. It has largely been facilitated by the introduction of small, low-cost pumps operated by diesel and kerosene (Kikuchi et al. 2003). Although, incentives provided by the state agencies, such as the Agriculture Development Authority, have played an important role in popularizing agro-wells, many farmers subsequently invested in wells without any external support (Karunaratne and Pathmarajh 2002; Panabokke and Perera 2005). The major contribution of agro-wells is supplementing of water for cash crops during the dry season, thereby helping to increase farmer income (Nagarajah and Gamage 1998; Karunaratne and Padmarajah 2002).

Extraction of groundwater through privately owned agro-wells is determined mainly by commercial objectives. Compared with water from direct rainfall or community-managed tanks, this is the most expensive option for the supply of water, and the cost is borne privately by individual farmers. The agro-well option requires substantial capital expenditure for the construction of the wells and regular operational costs for the fuel needed to pump the water. As a result, unlike the relatively low cost supply of water more or less uniformly available to all farmers from direct rainfall or commonly managed tanks, agro-wells are an option available only to farmers who can afford it. Therefore, water extracted from agro-wells is utilized only for high-value cash crops (such as chilli and onion) and the level of extraction is largely determined by the price of fuel.

Policy Implications

The unforeseen effects of global climate change introduce a new element of uncertainty to the ongoing process of climate adaptation in the dry zone areas. Although recent analysis of agro-meteorological data in the dry zone has not indicated any substantial change (increase or decrease) in the total availability of RF, there is evidence to indicate that the pattern of rainfall has become erratic over the past several decades (Punyawardena 2007). Many farmers also seem to have observed changes in the established pattern of RF, especially during the past few years. Losses to farmers due to unforeseen changes indicate that familiar strategies of adaptation may not be adequate to face the challenges posed by climate change. Therefore, the adaptive capacity of farmers has to be enhanced further.

Individually or jointly, farmers have to search for an innovative selection of voluntary adaptation measures. One option open to farmers is fine-tuning the available mix of long-term and short-term adaptation measures to face the emerging changes in an optimal manner. Another option is adopting technological innovations such as resilient crop varieties, improved agronomic practices, resource conservation techniques and protective forms of agriculture. Among the market-based instruments for facing the risk of climate shocks are, crop insurance packages, but these are yet to gain wide acceptance among farmers in Sri Lanka.

However, voluntary measures alone may not be sufficient, therefore policy support also has a role to play in helping farmers adapt to climate shocks. Farmers need the support of appropriate policy and institutional interventions that can enhance their adaptive capacity. Among other responses, they need government policy support for:

- coping with the added uncertainty caused by the relatively rapid rate of change that is likely to be involved with global climate change;[2]
- facing disasters that could be caused by an increased frequency of extreme events;
- filling the gaps in the traditional and institutional settings created by ongoing socioeconomic transformation; and
- creating an enabling environment for innovative measures of voluntary adaptation by introducing appropriate policy changes.

For instance, state agencies can reduce the burden of uncertainty by providing climate forecast information so that farmers can anticipate likely changes in the near future. Similarly, the government can enhance the farmers' capacity to face disasters by connecting farmers with the disaster management system that is gradually evolving in the country. Therefore, policymakers also have an important role to play here by introducing suitable interventions to enhance and facilitate the adaptation choices of farmers.

[2] Voluntary adaptation efforts described in the article seem to have evolved over a long period of time as responses to changes that took place at a relatively slow pace. The major difference of global climate change is that it seems to be taking place at a relatively rapid pace.

References

Abeyratne, E. 1956. Dryland Farming in Sri Lanka. *Tropical Agriculturist* 112: 191-229.

Aheeyar, M. M. M. 2001. 'Socioeconomic and Institutional Aspects of Small Tank Systems in Relation to Food Security'. In: *Proceedings of the Workshop on Food security and Small Tank Systems in Sri Lanka*, ed. H. P. M. Gunasena. Colombo, Sri Lanka: National Science Foundation. pp. 64-78.

Aluwihare, P. B.; Kikuchi, M. 1991. 'Irrigation Investment Trends in Sri Lanka: New Construction and Beyond'. Colombo, Sri Lanka: International Irrigation Management Institute (IIMI).

Amarasinghe, U. A.; Mutuwatta, L.; Sakthivadivel, R. 1999. *Water scarcity variations within a country'. A case of Sri Lanka*. IWMI Research Report 32. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Chakrabarty, R. D.; Samaranayake, R. A. D. B. 1983. Fish Culture in Seasonal Tanks in Sri Lanka. *Journal of Inland Fisheries* 2: 125-140.

Department of Census and Statistics. 2007. Statistical Abstract. Colombo, Sri Lanka: Department of Census and Statistics.

Handawala, J. 2004. 'Understanding Rainfall as a First Pre-requisite to Tank Management and Rehabilitation'. In: *Small Tank Settlements in Sri Lanka*, ed. M.M.M. Aheeyar. HARTI, Colombo, Sri Lanka: pp. 31-39.

Imbulana, K. A. U. S.; Wijesekara, N. T. S.; Neupane, B. R. (Eds.) 1986. Sri Lanka National Water Development Report. Colombo, Sri Lanka: Ministry of Agriculture, Irrigation and Mahaweli Development and UNESCO.

Karunaratne, A. D. M.; Pathmarajah, S. 2002. 'Groundwater Development through Introduction of Agro-wells and Micro Irrigation in Sri Lanka'. In: *Use of Groundwater for Agriculture in Sri Lanka*, ed. S. Pathmarajah. Department of Agricultural Engineering, University of Peradeniya, Peradeniya, Sri Lanka.

Kikuchi, M.; Barker, R.; Weligamage, P.; Samad, M. 2002. *Irrigation sector in Sri Lanka: Recent investment trends and the development path ahead*. IWMI Research Report 62. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Kikuchi, M.; Weligamage, P.; Barker, R.; Samad, M.; Kono, H.; Somaratne, P. G. 2003. *Agro-well and pump diffusion in the dry zone Sri Lanka*. IWMI Research Report 66. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Nagarajah, S.; Gamage, H. 1998. 'Groundwater Utilization for Crop Production in the Dry Zone Sri Lanka'. *Proceedings of a Symposium held in Kandy, Sri Lanka*. Natural Resources Management Center, Perdeniya, Sri Lanka.

Panabokke, C. R. 2001. 'Small Tank Systems in Sri Lanka: Summing and Issues'. In: *Proceedings of the Workshop on Food Security and Small Tank Systems in Sri Lanka*, ed. H.P.M. Gunasena. Colombo, Sri Lanka: National Science Foundation.

Panabokke, C. R.; Perera, A. P. G. R. L. 2005. Groundwater Resource of Sri Lanka, Water Resources Board, Colombo, Sri Lanka.

Punyawardena, B. V. R. 2007. Personal Communications.

Siriweera, W. I. 1994. 'A Study of Economic History of Pre-Modern Sri Lanka'. New Delhi, India: Vikas Publishing House.

Somasiri, S. 2001. 'Strategies for Optimizing Food Security under Small Tank Systems in Relation to the High Variability of the Resource Base'. In: *Proceedings of the Workshop on Food Security and Small Tank Systems in Sri Lanka*, ed. H. P. M. Gunasena. Colombo, Sri Lanka: National Science Foundation.

Tennakoon, M. U. A. 1986. 'Drought Hazard and Rural Development', Central Bank of Sri Lanka, Colombo, Sri Lanka.

Ulluwishewa, R. 1997. 'Searching Avenues for Sustainable Land Use: The Role of Indigenous Knowledge between Market Forces and State's Intervention'. *Sri Lanka Studies Vol*. 6. Swiss Agency for Development Cooperation (SDC).

Weerakoon, W. L.; Liyanage, M. D. S. 1987. 'Aspects of Conservation Farming.' Department of Agriculture, Maha Illuppallma Agricultural Research Station, Sri Lanka.

Potential to Increase the Area under Paddy Cultivation with Domestic and Municipal Wastewater Irrigation in Kurunegala District

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Abstract

Use of domestic wastewater for agriculture was a traditional practice in Sri Lanka where leafy vegetables and medicinal plants were cultivated in backyards. The use of domestic and municipal wastewater could be an environmentally sound means of wastewater disposal and could reduce environmental pollution if utilized for paddy irrigation. This practice could also help to increase the economic productivity of the water and land. Therefore a study was conducted in selected Divisional Secretariat Divisions in Kurunegala District in order to explore the potential for land to be brought under paddy cultivation with the utilization of municipal and domestic wastewater. The quantity of wastewater generated was estimated based on the population and water consumption data. Data on the extent of paddy land under minor irrigation and rain-fed agriculture, potential cultivable land extent (known as asweddumized area), land area cultivated in *maha* (wet) and *yala* (dry) seasons, and the areas harvested were collected from the District Agriculture Department. It is noted that not all the available lands were cultivated and harvested in both the *maha* and *yala* seasons. The area of land that is not used for any crop production is higher in the *yala* season than in the *maha* season. In addition, only a part of the land area is harvested from the total area sown. Major reasons for crop failure are inadequate rainfall and shortage of supplementary irrigation water. The difference between the cultivable (asweddumized) extent and harvested extent shows the land that can potentially be brought under irrigation using municipal and domestic wastewater. The amount of land that can be so irrigated is much higher closer to the city where the storm water and other forms of wastewater are drained through common canal systems. Depending on the quantity and quality, and the availability of fresh irrigation water, municipal wastewater can be either diluted with irrigation water to meet the total irrigation water requirement, or can be used without any dilution. In addition to the increment of the land area under cultivation, there is a possibility of increasing the cropping intensity.

Introduction

Traditionally, domestic wastewater generated in villages in Sri Lanka, especially grey-water from kitchens, bathrooms and washrooms, flows along open unlined wastewater drains and is collected in a pool, before being used to irrigate leafy vegetables and medicinal plants. The crops benefited not only from the water but also the nutrients that the wastewater contained. Such a system of wastewater disposal and utilization was separated from the black-water (toilet water) disposal system so that the grey-water used for wastewater irrigation would not be contaminated with harmful deposits (pathogens). Urbanization has increased concerns over the effects of expanding cities, principally on human health, livelihoods and the environment. Water supply and waste disposal systems are unable to keep pace with the development under resource-poor environments, as is the case in developing countries. Once urbanization starts, land becomes too limited for the traditional wastewater disposal mechanisms that are practiced in rural areas. The grey-water that is generated is disposed of mostly into storm water drains, irrigation canals or natural waterways. The wastewater collected in the drains or canals gets diluted with the storm water or irrigation water during certain periods of the year but is concentrated at other times, depending on the amount of rain received and irrigation water releases.

An emerging issue in such areas is the use of diluted wastewater in irrigation, resulting from wastewater pollution of the original irrigation water sources (Raschid-Sally et al. 2006). Using such wastewater in urban and peri-urban agriculture may support the livelihoods of the urban poor and improve productivity, which in turn improves food supplies to cities, despite the health and environmental risks associated with this practice. The common attraction of such a system of diluted wastewater irrigation is not just that it provides a source of water for irrigation, but also that it offers a source of nutrient value. Wastewater use in agriculture in the context of less-developed countries is clearly, therefore, the result of poor urban sanitation. However, the use of wastewater in agriculture offers economic and environmental benefits relative to the costs of not using it.

Insufficient information is available in Sri Lanka on the quantities of wastewater generated and extent of wastewater irrigation in the country as a whole. Therefore, as part of a global survey on wastewater irrigation and agriculture practices, three cities in Sri Lanka were studied, namely Anuradhapura, Kandy and Kurunegala, to quantify the extent and significance of wastewater use. The study also looked at the effect on livelihoods and the range of conditions and factors that influence wastewater use in agriculture (Raschid-Sally and Jayakody 2008).

Urban wastewater is used in agriculture as an alternative to its direct disposal to the sea or surface water bodies. Urban wastewater may be a combination of some or all domestic effluent consisting of black-water (excreta, urine and associated sludge) and grey-water (kitchen and bathroom wastewater), water from commercial establishments and institutions, including hospitals, industries, storm-water and other urban runoff (Van der Hoek 2004). Wastewater agriculture is viewed as a hazard to the health of irrigators as well as the consumers of wastewater irrigated products; and wastewater agriculture may affect the environment too.

Based on a hypothetical consumptive use of 20-40 % for urban areas, it can be assumed that on average 70 % of urban water returns as wastewater, which is an internationally accepted figure for wastewater return flows. There can be variations in this amount according to factors such as the geographical location of cities, the climate, people’s behavior, level of industrialization and the number of people served with pipe-borne water. According to the Sri

Lanka Standard (SLS) 745-2003 for 'design and construction of septic tanks and associated effluent disposal systems' (Sri Lanka Standards Institution, SLSI 2003), average wastewater generation is 240-160 liters/capita/day (lcd), of which 75 % is grey-water and 25 % is black-water. This figure can be used to estimate the quantity of wastewater that is potentially available for use per capita, based on consumption data. On average, the National Water Supply and Drainage Board (NWSDB) consider water consumption to be 120 lcd. The estimate of the annual total wastewater generation in the country is, therefore, 273 million cubic meters (MCM) according to a study by Jayakody et al. (2006). A major part of this volume is diverted to the sea or surface water bodies.

Wastewater use is viewed as a benefit providing livelihoods and perishable food to cities. Leafy vegetable cultivation with wastewater is reported in peri-urban areas around Colombo using wastewater that is derived mainly from water in drainage canals. In Kurunegala, peri-urban paddy cultivation using diverted municipal wastewater takes place in both cultivable areas of land and surrounding areas. It is noted that not all the available lands were cultivated and harvested in both the *maha* (wet) and *yala* (dry) seasons (Jayakody et al. 2006). The land area which is not used for any production is very high in the *yala* season compared to the *maha* season. As an example, cultivable lands available near Kurunegala City are 2,002 ha but only 1,971 ha are sown in *maha* and 1,143 ha in *yala*. About 1,675 ha in *maha* and 1,052 ha in *yala* reached harvest stage, and the rest failed due to water scarcity (inadequate rainfall and irrigation water). Therefore, a study was conducted in selected Divisional Secretariat (DS) Divisions in the Kurunegala District in order to explore the potential increase in land that can be brought under paddy cultivation with the utilization of municipal and domestic wastewater.

Methodology

Kurunegala District, which is one of the major paddy growing areas within the intermediate zone, was selected for this study. Data from all the DS Divisions within Kurunegala District was collected from different sources such as the Provincial Agriculture Department, the Department of Census and Statistics (DCS), and published literature. Data on the extent of paddy lands under major and minor irrigation and under rain-fed agriculture, their potential cultivable extent, land area cultivated in maha and yala seasons and the areas harvested were collected from the DCS.

Wastewater generation in each DS Division was estimated based on the population and water consumption data. The population data (2001 census) was collected from the DCS and was combined with the NWSDB water consumption to estimate the quantities of probable grey-water discharges.

The water requirement of paddy for Kurunegala District was estimated using data on the rate of evaporation in Kurunegala and the paddy crop coefficient using the peak water requirement at the mid-season stage. It is assumed that the water required for land preparation is supplied mainly by rainfall.

Results and Discussions

Kurunegala District and the Climatic Zones

Kurunegala District is located mainly within the intermediate zone of Sri Lanka, (the area that is defined by climatic conditions that vary between dry and wet in terms of rainfall). It has an annual rainfall of 1,450 mm to 2,400 mm. The major rainy seasons in Kurunagala are April to June (*yala*, dry season) and September to December (*maha*, wet season), with most rain being received during March to May and October to December. Other months are mainly considered to be dry months. The intermediate climatic zone receives more rainfall than the other parts of the District, which fall within the dry zone. The rainfall received in a month within the rainy seasons varies widely and the rainfall received in certain months is not sufficient to fulfill the crop water requirement. As such the need for a supplementary source of water for irrigation becomes essential during such periods.

Paddy Cultivation in the Kurunegala District

There are 77,690 ha of cultivable paddy lands in Kurunegala District of which 12,928 ha are under major irrigation schemes, 34,576 ha are under minor irrigation schemes and the remainder (30,186 ha) are under rain-fed paddy cultivation (Table 1). In the maha season 94.4 % of the area is cultivated but only 45.2 % is cultivated in the yala season. In the yala season 80.3 % of the major irrigated areas are cultivated but the area under cultivation is very low for the minor irrigated areas (49.8 %) and rain-fed areas (24.8 %), mainly due to water shortages. This is seen by the fact that even in the few areas that are cultivated, almost 100 % are harvested in the maha season, as there is no water shortage during that time that could cause crop failure, but during the drier yala season, 95 % of the area is not harvested.

The extents of land that are not sown in the maha season under the minor irrigation schemes and under rain-fed cultivation is 5.4 % and 7.4 %, respectively (Table 1). Under the major irrigation schemes the extent not sown is very low and is mainly due to poor availability of sufficient supplementary water for irrigation under the irrigation tank scheme or the river water diversion scheme.

During the *yala* season, the extent of land under the major schemes that is not sown increases from 1.8 % to 19.7 % (Table 1). This considerable increase is mainly due to the shortage of water in the reservoir or the insufficiency of water in the river for diversion. Under the minor irrigation schemes, the extent of lands not sown increases from 5.4 % to 50.2 %, mainly due to insufficient irrigation water in the minor tank systems or the anicut schemes. The low rainfall in the area contributes to the lower water level in the minor reservoirs. The rain-fed agriculture is the worst affected sector in the *yala* season, where 75.2 % of the lands are not cultivated (Table 1). This is mainly due to insufficient rainfall for a paddy crop.

Table 1. Extent of lands in *maha* and *yala* in Kurunegala District.

		Asweddumized	Sown	Not Sown	Harvested	Not Harvested
	Major (ha)	12,928	12,691	237	12,691	0
	(%)		(98.2)	(1.8)	(100.0)	(0.0)
Maha	Minor (ha)	34,576	32,699	1,877	32,636	63
	(%)		(94.6)	(5.4)	(99.8)	(0.2)
	Rain-fed (ha)	30,186	27,942	2,244	27,879	63
	(%)		(92.6)	(7.4)	(99.8)	(0.2)
	Total	77,690	73,332	4,358	73,206	126
	(%)		(94.4)	(5.6)	(99.8)	(0.2)
	Major (ha)	12,928	10,387	2,541	9,868	519
	(%)		(80.3)	(19.7)	(95.0)	(5.0)
Yala	Minor (ha)	34,576	17,221	17,355	16,360	861
	(%)		(49.8)	(50.2)	(95.0)	(5.0)
	Rain-fed (ha)	30,186	7,484	22,702	7,110	374
	(%)		(24.8)	(75.2)	(95.0)	(5.0)
	Total	77,690	35,092	42,598	33,338	1,754
	(%)		(45.2)	(54.8)	(95.0)	(5.0)

Wastewater Generation in the Kurunegala District

The NWSDB takes 120 lcd as the water consumption figure. According to the Sri Lanka Standard Institution (SLSI), the amount of grey-water generated is 75 % of the water used (SLSI 2003). Considering these two values, the amounts of grey-water generated at each DS division is estimated and given in Table 2.

Table 2. Estimated wastewater generation in DS Divisions in Kurunegala District.

DS Division	Population	Amount of grey-water generation (Liters/Day)	Amount of grey-water generation (m^3/Day)	55 % of grey-water that can be diverted (m^3/Day)
Alawwa	59,082	5,317,380	5,317.38	2,924.6
Ambanpola	19,964	1,796,760	1,796.76	988.2
Bamunakotuwa	20,702	1,863,180	1,863.18	1,024.7
Bingiriya	55,763	5,018,670	5,018.67	2,760.3
Ehetuwewa	23,076	2,076,840	2,076.84	1,142.3
Galgamuwa	47,844	4,305,960	4,305.96	2,368.3
Ganewatta	36,812	3,313,080	3,313.08	1,822.2
Giribawa	28,093	2,528,370	2,528.37	1,390.6

(continued)

Table 2. Estimated wastewater generation in DS Divisions in Kurunegala District. *(continued)*

DS Division	Population	Amount of grey-water generation (Liters/Day)	Amount of grey-water generation (m^3/Day)	55 % of grey-water that can be diverted (m^3/Day)
Ibbagamuwa	76,344	6,870,960	6,870.96	3,779.0
Katupotha	27,575	2,481,750	2,481.75	1,365.0
Kobeigane	32,230	2,900,700	2,900.7	1,595.4
Kotavehera	19,273	1,734,570	1,734.57	954.0
Kuliyapitiya East	46,966	4,226,940	4,226.94	2,324.8
Kuliyapitiya West	71,483	6,433,470	6,433.47	3,538.4
Kurunegala	88,944	8,004,960	8,004.96	4,402.7
Maho	50,576	4,551,840	4,551.84	2,503.5
Mallawapitiya	46,575	4,191,750	4,191.75	2,305.5
Maspotha	18,850	1,696,500	1,696.5	933.1
Mawathagama	56,820	5,113,800	5,113.8	2,812.6
Narammala	51,244	4,611,960	4,611.96	2,536.6
Nikaweratiya	36,370	3,273,300	3,273.3	1,800.3
Panduwasnuwara	69,888	6,289,920	6,289.92	3,459.5
Pannala	114,438	10,299,420	10,299.42	5,664.7
Polgahawela	58,762	5,288,580	5,288.58	2,908.7
Polpithigama	67,263	6,053,670	6,053.67	3,329.5
Rasnayakapura	18,814	1,693,260	1,693.26	931.3
Rideegama	80,473	7,242,570	7,242.57	3,983.4
Udubaddawa	48,800	4,392,000	4,392	2,415.6
Wariyapola	56,880	5,119,200	5,119.2	2,815.6
Weerambugedara	30,311	2,727,990	2,727.99	1,500.4
Kurunegala District	1,460,215	131,419,350	1,31,419.35	

In Kurunegala DS Division, the grey-water generated is estimated to be 8,005 m^3/day and the amount of grey-water generated in Kurunegala City is 4,620 m^3/day, approximately 55 % of the total (Ranaweera 2005). This wastewater flows through storm water drains or natural streams that pass through the city and could be collected and diverted to irrigate paddy fields.

Paddy Water Requirement

For a 110 paddy variety, the crop water requirement is 445 mm in *yala* season and 325 mm in *maha* season. The seepage and percolation loss is about 4 mm/d, amounting to about 380 mm for a cropping season. The peak irrigation water requirement is 7.72 mm/d in *maha* and 8.08 mm/d in *yala* in Kurunegala. The crop water requirement is estimated based on the crop coefficients given in Allen et al. (1998) and average pan evaporation values in Kurunegala (Imbulana et al. 2006). Due to the dry climatic conditions, the crop water requirement in *yala* season is more than the *maha* season. This is one of the reasons why the extent of paddy cultivated is less during *yala* as the available water in the reservoirs is limiting. The amount of rainfall received is also less during the *yala* season.

Potential Paddy Cultivable Area with Grey-water Irrigation

Considering the peak irrigation water requirement, the extent of extra land that can be cultivated in *yala* and *maha* is given in Table 3. About 20 % of the uncultivated lands in *maha* can be brought under cultivation if 55 % of the grey-water generated is collected and diverted to irrigate paddy fields. In the *yala* season, only a very small portion of uncultivated land (2.2 %) can be brought under cultivation with grey-water irrigation.

Table 3. Extent of extra land that can be cultivated with grey-water in Kurunegala District.

DS Division	Harvested / Diverted Grey-water (m^3/d)	Cultivable extent (ha) *Yala*	*Maha*
Alawwa	2,924.6	37.9	36.2
Ambanpola	988.2	12.8	12.2
Bamunakotuwa	1,024.7	13.3	12.7
Bingiriya	2,760.3	35.8	34.2
Ehetuwewa	1,142.3	14.8	14.1
Galgamuwa	2,368.3	30.7	29.3
Ganewatta	1,822.2	23.6	22.6
Giribawa	1,390.6	18.0	17.2
Ibbagamuwa	3,779.0	49.0	46.8
Katupotha	1,365.0	17.7	16.9
Kobeigane	1,595.4	20.7	19.7
Kotavehera	954.0	12.4	11.8
Kuliyapitiya East	2,324.8	30.1	28.8
Kuliyapitiya West	3,538.4	45.8	43.8
Kurunegala	4,402.7	57.0	54.5
Maho	2,503.5	32.4	31.0
Mallawapitiya	2,305.5	29.9	28.5
Maspotha	933.1	12.1	11.5
Mawathagama	2,812.6	36.4	34.8
Narammala	2,536.6	32.9	31.4
Nikaweratiya	1,800.3	23.3	22.3
Panduwasnuwara	3,459.5	44.8	42.8
Pannala	5,664.7	73.4	70.1
Polgahawela	2,908.7	37.7	36.0
Polpithigama	3,329.5	43.1	41.2
Rasnayakapura	931.3	12.1	11.5
Rideegama	3,983.4	51.6	49.3
Udubaddawa	2,415.6	31.3	29.9
Wariyapola	2,815.6	36.5	34.8
Weerambugedara	1,500.4	19.4	18.6
Total		936.5	894.5

Potential Risks of Wastewater Irrigation and Possible Mitigation Measures

Using wastewater to cultivate leafy vegetables may cause many health risks to the consumers as well as the producers. The risks could be mainly due to the contamination of wastewater with black-water or faecal matter. The major health risks would be diarrheal diseases, skin diseases and worm infections for consumers and producers.

In many towns there is a risk of contamination where the municipal wastewater is a mixture of grey-water, yellow-water, and black-water and in some instances industrial wastewater. Industrial wastewater generated by certain industries might contaminate the water with heavy metals that could bio-accumulate in the products consumed.

In addressing these health risks, the state and local government authorities have to play a major role. Sanitation infrastructure needs to be planned, installed and maintained according to the standards set and infrastructure and facilities must comply with environmental regulations. In order to make the agricultural use of wastewater possible, the authorities have to prevent black-water and industrial wastewater from contaminating the viable grey-water and storm water.

The authorities could also regulate crop selection for wastewater irrigation, in that the growth of vegetables with wastewater, especially leafy vegetables, should be discouraged or prohibited while the cultivation of cereals should be encouraged, as the product of the latter is not in direct contact with the wastewater and is never eaten uncooked. Further, the farming community who utilizes wastewater for agriculture should be made aware of the health risks they face and empowered with the knowledge to minimize such risks.

Conclusion

Wastewater agriculture is practiced in very few localities in Sri Lanka, and where it is, it is practiced informally. There are a few places where wastewater is diverted to cultivate paddy but the extent cultivated is very small. This study shows that if the wastewater generated in cities, especially the grey-water from domestic water use, can be collected and diverted for agricultural production, areas that are uncultivated due to water shortage can be brought under cultivation. The land extent that can be brought under paddy cultivation is about 936 ha in the *maha* season and 895 ha in the *yala* season in the Kurunegala District. The authorities must, however, ensure that the grey-water that is diverted for agricultural production is not contaminated with black-water and hazardous industrial wastewater in order to minimize the adverse health risks that could affect farmers using wastewater agriculture and consumers using the products of wastewater agriculture.

References

Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M. 1998. 'Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements'. FAO Irrigation and Drainage Paper 56., Rome, Italy: Food and Agriculture Organization of the United Nations.

Imbulana, K. A. U. S.; Wijesekera, N. T. S.; Neupane, B. R. 2006. 'Sri Lanka National Water Development Report'. UNESCO and Ministry of Agriculture, Irrigation and Mahaweli Development, Sri Lanka.

Jayakody, P.; Raschid-Sally, L.; Abayawardana, S. A. K.; Najim, M. M. M. 2006. 'Urban Growth and Wastewater Agriculture: A study from Sri Lanka', 32nd WEDC International Conference, Colombo, Sri Lanka.

Ranaweera, R. A. D. U. P. 2005. 'Wastewater Generation, Its Quality and Conjunctive use for Paddy Irrigation in Kurunegala', Peradeniya, Sri Lanka: BSc. Thesis Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya.

Raschid-Sally, L.; Jayakody, P. 2008. *Drivers and characteristics of wastewater agriculture in developing countries: Results from a global assessment*. IWMI Research Report 127. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Raschid-Sally L.; Kegne, I. M.; Viet Anh, N.; Endamana, D. 2006. 'Wastewater Use in High Rainfall Riverine Cities: Comparisons from Cameroon, Nepal and Vietnam'. International survey of wastewater reclamation and re-use practice. Published by the International Water Association.

SLSI (Sri Lanka Standards Institution). 2003. 'Draft Sri Lanka Standard - Code of Practice for the Design and Construction of Septic Tanks and Associated Effluent Disposal Systems'. Colombo, Sri Lanka: Sri Lanka Standards Institution.

Van der Hoek, W. 2004. 'A framework for a Global Assessment of the Extent of Wastewater Irrigation: The Need for Common Wastewater Typology'. Wastewater use in irrigated agriculture confronting the livelihood and environmental realities. CABI publication.

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166. D. J. Bandaragoda. 449, Pansala Para, Thalawatugoda.
167. Sarath Abayawardana, CEO, National Science Foundation. 47/5, Maitland Place, Colombo 7.

Related Publications

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www.iwmi.org/Publications/Other/PDF/Final%20Booklet%201-Service%20Stations.pdf

Dissanayake, P.; Tennakoon, M. 2008. ***Guide to on-site wastewater management for industrial and commercial establishments and other institutions: guide for hotel and restaurant owners and managers in Kurunegala, Sri Lanka.*** Colombo, Sri Lanka: International Water Management Institute (IWMI). 31p.

www.iwmi.org/Publications/Other/PDF/Final%20WASPA%20Booklet%202-Hotels.pdf

Dissanayake, P.; Smakhtin, V. 2007. ***Environmental and social values of river water: examples from the Menik Ganga, Sri Lanka.*** Colombo, Sri Lanka: International Water Management Institute (IWMI). 15p. (IWMI Working Paper 121)

www.iwmi.org/Publications/Working_Papers/working/WOR121.pdf

Panabokke, C. R.; Ariyaratne, B. R.; Seneviratne, A.; Wijekoon, D.; Molle, F. 2007. ***Characterization and monitoring of the regolith aquifer within four selected cascades (sub-watersheds) of the Malala Oya Basin, Sri Lanka.*** Colombo, Sri Lanka: International Water Management Institute (IWMI). 38p. (IWMI Working Paper 122)

www.iwmi.org/Publications/Working_Papers/working/WOR122.pdf

Smakhtin, V.; Weragala, N. 2005. ***An assessment of hydrology and environmental flows in the Walawe River Basin, Sri Lanka.*** Colombo, Sri Lanka: International Water Management Institute (IWMI). 13p. (IWMI Working Paper 103)

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ISBN 978-92-9090-722-0